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AN EXPERIMENTAL STUDY OF HYPNOTIC ANESTHESIA [1]

BY ROBERT R. SEARS

Yale University

The chief historical significance of hypnotic anesthesia lies in its limited use for alleviating surgical pain prior to 1844. In that year the anesthetic properties of nitrous oxide were discovered and hypnosis was largely displaced from its precarious position in popular favor. In recent years, however, it has come into rather widespread use in Germany for obstetrical work. Little data concerning its effectiveness in this field other than descriptions of cases are available.

An important question is raised by Neutra (**8**), a German obstetrician. He states that hypnosis should be used only when general anesthesia is definitely contra-indicated, since post-operative or post-delivery shock is greater following hypnosis. If this is true, or if it is true that hypnotic anesthesia does not greatly reduce the shock of trauma and normal responses to injury (pain), there would be an indication that hypnotic anesthesia consists of little else than a voluntary inhibition of the usual symbolic or verbal reactions to pain.

Bechterev (**1**), however, in searching for an objective criterion of the presence of hypnotic anesthesia, observed that when analgesia was suggested, stimulation by pricking did not elicit the normal respiratory, cardiac, or pupillary reactions

[1] This problem was suggested by Dr. Clark L. Hull. The author wishes to express his appreciation for Dr. Hull's generous assistance and criticism during the experiment.

to pain. The two latter processes have usually been considered as beyond voluntary control. Bechterev does not state his method of measuring these functions, or what he believes the normal responses to be, but gives several references in Russian which presumably contain the data from which he draws his conclusions.

Lundholm (7) found that in a case of suggested visual anesthesia, the eye-turning response did not appear when a light was flashed near the subject's eyes but the pupillary reflex was present. Likewise, with a positive visual hallucination of a bright light, the eye-turning response appeared but there was no pupillary reflex. The same investigator found also that under post-hypnotic auditory anesthesia a conditioned retraction of the finger from an electric shock to clicking of a telegraph key broke down. He states that after an hour of questioning in the trance he reached an 'integrate of the S's personality' in which was located an 'inhibition' to reacting to the 'heard' sound. This apparently is an admission of voluntary control of verbal processes, but the present writer would be suspicious of any confession received from a subject after an hour in the trance state. There is thus little agreement between the findings of Neutra, Lundholm, and Bechterev.

It has been the purpose of the present study to discover at what psycho-physiological levels, and to what quantitative extent, hypnotic anesthesia is able to inhibit or otherwise modify the ordinary reactions to pain stimuli.

Procedure [2]

Five types of activity were chosen for measurement. These range from easily inhibited to more purely non-voluntary processes.

1. *Facial Grimace.*—In a preliminary experiment it was found that there is a characteristic facial twitch in response to sudden pricking pain. It consists of a sharp vertical movement of the skin surrounding the outer corner of the eye.

[2] The procedure employed here follows to a considerable extent that outlined by Hull (4): Quantitative Methods of Investigating Hypnotic Suggestion, *J. Abn. and Soc. Psych.*, 25, 1930. See especially projects Nos. 25, 55, 56, 57, 58 and 59.

This act may be performed voluntarily and may be inhibited by most people with little difficulty, though it is normally present as a response to pain.

2. *Reflex Leg Withdrawal.*—This is a semi-voluntary defense reaction. It consists of a slight withdrawal motion of the member of the body which is stimulated, in this case the legs. Although it may be slightly less voluntary than the facial twitch it can usually be inhibited without great difficulty.[3]

3. *Respiration.*—A marked change in the pattern of respiratory activity has been long recognized as a concomitant of painful stimulation. This fact lends color to Foerster's statement (**3**, 1) that pain 'belongs to that group of psychological phenomena which are to be classified as feelings and emotions rather than as sensations and perceptions.' Breathing may also be classified as a semi-voluntary process but probably of a somewhat lower level than that of leg withdrawal.

4. *Pulse Activity.*—The pattern of the pulse tracing changes markedly after a painful stimulus. This appears to be a purely non-voluntary process in the sense that it is rarely possible to control the circulatory activity directly. Indirect control may be achieved by autostimulation of the emotions.

5. *Galvanic Skin Reaction.*—So far as the present writer knows, the completely non-voluntary nature of this phenomenon as an emotional reaction has never been questioned.

Apparatus

1. *Facial Grimace.*—A special chair was constructed with a high backboard on which was affixed a curved headrest made of sheet metal padded with felt. This was adjusted to the height of the subject's head and prevented gross head movements during the experiment. In addition, the subject was instructed to hold his head as still as possible.

In the arm of the chair a vertical metal rod was inserted

[3] A mechanical artifact was discovered in the recording of this reaction. These results have not, therefore, been included in this report.

that came within 8 inches of the subject's head. To this was clamped a Marey tambour with stylus of thin aluminum (Fig. 1). The end of the stylus was bent at a 90-degree angle. When the tambour was fixed in place, the flattened bent end of the stylus fit snugly against the facial muscles at the outer corner of the right eye. This receiving tambour was connected by air transmission with a recording tambour fitted with Krueger's non-distorting stylus (**6**): thus, any facial movement was indicated by a vertical mark on the kymograph record (see Fig. 3, *B'*).

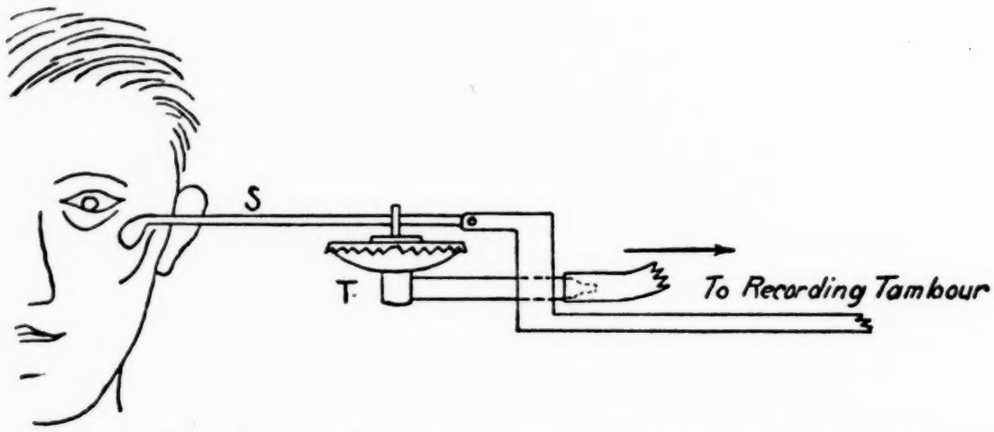

FIG. 1. Device for recording facial grimace. The tambour (*T*) is mounted on a vertical rod opposite cheek of subject. Aluminum stylus (*S*) is bent at a 90 degree angle and fits snugly against the muscles below outer corner of eye. Movement of facial muscles is recorded on smoked paper by air transmission to a recording tambour.

2. *Respiration.*—A Sumner pneumograph, placed over the 8th rib, was used with a recording tambour and Krueger's stylus.

3. *Pulse Activity.*—An Erlanger-Meek Recording Sphygmomanometer was used. This instrument has a stylus which traces the record on smoked paper in the conventional manner. The problem of arc distortion is not serious, however, because of the small amplitude of the tracing.

4. *Galvanic Skin Reaction.*—Two Ostwald non-polarizable electrodes were mounted close together in the right arm of the subject's chair. The index and ring fingers of the subject's right hand were placed in the liquid of these electrodes. Leads were taken off to a D'Arsonval wall galvanometer. No exosomatic current was used. A beam of light was reflected

from the galvanometer's mirror onto a semi-transparent celluloid screen. An assistant [4] followed this spot of light with a small pointer which slides horizontally on a bar at the base of the screen. To the pointer was attached a thread which ran through a pulley system to a thin rod, with stylus attached, moving vertically in a sleeve beside the kymograph. The rod was suspended from a support by a twisted rubber band. This provided torsion enough to hold the stylus firmly against the kymograph drum. It acted also as a spring to pull the rod and stylus up when the pointer at the base of the screen was moved toward the thread instead of away from it (**2**).

A Recording Pain Stimulator.—The apparatus devised for stimulating the subject so as to produce pain and the concomitant psycho-physiological reactions is shown in Fig. 2. It consists of a sharp steel point (*A*) inserted, at the angle shown, into a metal rod. This rod (*B*) slides easily in a tube (*C*). A transverse pin (*E*) at the upper end of the tube holds in place a small coil spring (*D*) against which the rod rests. Pressure on the point of the stimulator forces the rod against the spring, which causes a resistance of 10 ozs. when the notch at (*a*) reaches the end of the tube, and 20 ozs. when the notch at (*b*) reaches it. Depression of the spring is accompanied by increased air pressure in the rubber tubing (*F*), which leads to a recording tambour and stylus. Thus the delivery of the stimulus is automatically recorded on the smoked paper.

An area of 2 sq. inches on the calf of each leg was used as the locus of stimulation. The point is placed against the skin so the tube is perpendicular to the surface of the leg. The point consequently presses against the skin at an angle of 45 degrees. This stimulator produces greater pain than a sharp point pressed vertically against the skin and will not penetrate the tissue. This eliminates danger of infection and probably allows the spot stimulated to return within a short time to its normal condition as a pain receptor. Each stimulus consisted of 20 ozs. pressure lasting about 1 second.

[4] The writer wishes to acknowledge the assistance of Miss Helen Hope.

In marking the records for measurement a vertical line was drawn through the point at which the pain line first showed the sharp rise resulting from depression of the spring (see Fig. 3, *C'*).

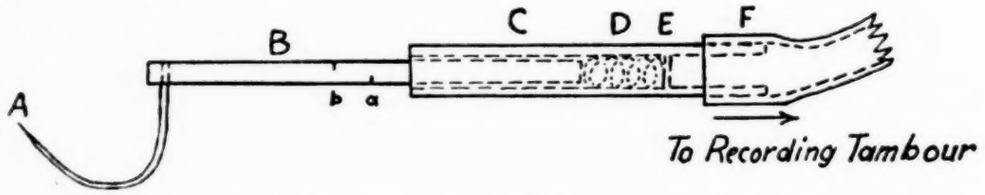

FIG. 2. Recording pain stimulator. (*A*) sharp steel point to be pressed against skin at 45 degree angle; (*B*) metal rod sliding in sleeve (*C*) against coil spring (*D*); (*E*) transverse pin against which spring rests; (*F*) rubber tube to recording tambour, allowing automatic recording of stimulus; (*a*) calibration for 10 oz. pressure; (*b*) calibration for 20 oz. pressure.

METHODS OF CONTROL

Both legs were used for stimulation, the left for experimental purposes and the right as a control. The procedure divides into three parts: (1) Waking Series—a preliminary control series in the waking state to determine whether stimulation of both legs would cause the same reactions; (2) Trance Series—the main experimental series in the trance state in which the left leg was suggested analgesic and the right leg was left normal as a control; (3) Voluntary Inhibition Series—a final control series, partly in trance and partly in waking state, during which the subject was instructed to inhibit all reactions to the painful stimulus in his left leg, but to react normally to pain in his right leg. There was no suggestion of anesthesia. This last series was carried out to discover whether simulation (voluntary inhibition) could produce the same picture at any or all levels of measurement as was produced by suggested anesthesia itself.

TECHNIQUE

The subject was requested to close his eyes during the Waking Series. Stimulations were given in the *A B B A* order, beginning with the left leg, and were from 50 to 80 secs. apart. A definite rhythm of stimulation was avoided in order that each stimulus might have approximately the same

quality of unexpectedness, and that temporal conditioning might not interfere. Four to ten stimulations were given in this series at each of three experimental periods.

There followed a 5-min. pause while the trance was being induced. During this period the arm-band of the sphygmograph was loosened and the fingers of the right hand were taken from the electrodes.

The trance was induced by instructing the subject to fixate the tip of the experimenter's finger, which was held about ten inches in front of the subject's eyes; the usual trance suggestions of relaxation, sleep, etc., were given.

Anesthesia was then induced with the following suggestions:

"I am going to take all the sensation out of your left leg. You will be able to feel absolutely nothing that touches it; all the feeling will be gone. Now I am sliding my hand along the calf of your leg. Each time I do this my hand will feel lighter and lighter. All the sensation is going. It's going; it's going! Now you can scarcely feel my hand; it is just like feathers brushing your leg. (Strength is lent this suggestion by allowing the hand to brush along the hairs of the leg without touching the skin.) Now all the feeling is gone. You cannot tell when I touch your leg and you can feel absolutely no pain when I prick it."

The pressure of the experimenter's hand actually grows less, of course, near the end of the suggestions.

Eight to 16 stimulations were given in *A B B A* order, beginning with the anesthetic (left) leg. When more than 8 stimuli were given, a 5-min. rest was introduced after the 8th in order to relieve possible discomfort from the arm-band of the sphygmograph.

The Control Series involving voluntary inhibition was made some days after all the Waking and Trance Series had been completed.

Subjects.—Seven male university students were used as subjects. Six were undergraduates in their freshman and sophomore years and were paid for their services. The seventh (Ta) was a second-year medical student who served voluntarily. The first six had been trained to go into a deep trance for an experiment on post-hypnotic amnesia. All were somnambules, showing post-hypnotic suggestibility.

Just before the Voluntary Inhibition series was under-

taken, information from what was regarded as a reliable source came to hand, indicating that Subject M possessed marked paranoid tendencies. As a consequence experimental work with him was discontinued. There is accordingly no control record for this subject.

Results

1. *Facial Grimace.*—A simple positive or negative scoring was used for the facial flinching. That is, the flinch was scored either as present or as not present following a stimulation.

Table 1 shows, for each subject, the number of stimulations given on each leg in the three experimental series. The number of perceptible flinches resulting are also shown, and, in parentheses following these figures, are given the percentage values of the number of flinches in comparison with the number of stimulations given. At the foot of the table are given the means of these percentage values.

The difference between the means for the two legs in a given experimental series indicates the difference in their sensitivity as measured by the flinch response.[5]

It will be seen that in the Waking Series this difference is only 3.14 percent, P.E. 2.78. The critical ratio $\frac{D}{(\text{P.E.}_D)}$ is only 1.13. In other words, under normal waking conditions, the two legs are approximately equal in sensitivity, as measured by the facial grimace. In the Trance Series, however, the difference between the normal leg (right) and the anesthetic leg (left) is 27.86 percent. The curious reversal of reaction on the part of Subject Co causes a negative correlation and consequently a large P.E. for this difference (7.19), but the critical ratio is nevertheless 3.87, which indicates a decidedly reliable difference between the sensitivity of the two legs as measured by the flinch.

[5] The P.E. of this difference is obtained by use of the formula:

$$\text{P.E.}_D = \sqrt{\text{P.E.}_A^2 + \text{P.E.}_B^2 - 2r\,\text{P.E.}_A\,\text{P.E.}_B}$$

The "r" is derived by correlating the column of percentage values for one leg with the column for the other leg.

TABLE 1

FACIAL GRIMACE

In parallel columns are shown the number of pain stimulations given and the number of perceptible resulting flinches from each leg stimulated during the three experimental series. At the bottom are shown for the several experimental conditions the percentages of stimulations which caused flinching, the difference between the two legs in this respect, and the P.E. of this difference.

Subject	Waking Series				Trance Series				Control Series			
	Right Leg		Left Leg		Normal Leg		Anesth. Leg		Normal Leg		Vol. Inhib.	
	No. of Stims.	No. of Flinches	No. of Stims.	No. of Flinches	No. of Stims.	No. of Flinches	No. of Stims.	No. of Flinches	No. of Stims.	No. of Flinches	No. of Stims.	No. of Flinches
Cl.	12	0 (0%)	11	0 (0%)	14	1 (7%)	14	1 (7%)	12	1 (8%)	12	1 (8%)
Co.	6	2 (33)	6	2 (33)	20	0 (0)	20	2 (10)	8	0 (0)	8	0 (0)
L.	10	3 (30)	9	1 (11)	16	3 (19)	16	0 (0)	9	0 (0)	8	0 (0)
M.	7	6 (86)	7	7 (100)	12	9 (75)	12	0 (0)	—	—	—	—
S.	4	2 (50)	4	2 (50)	11	5 (45)	10	0 (0)	12	6 (50)	10	3 (30)
Ta.	6	6 (100)	6	5 (83)	21	11 (52)	20	0 (0)	9	7 (78)	9	7 (78)
Tr.	4	3 (75)	4	3 (75)	7	1 (14)	7	0 (0)	9	7 (78)	10	9 (90)
Mean percent of total stimulations causing flinches	53.43		50.29		30.28		2.42		35.66		34.33	
P.E.$_M$	8.36		8.90		6.49		1.00		9.40		10.01	
Diffs. (in %)	3.14 ± 2.78				27.86 ± 7.19				1.71 ± 2.80			
$\frac{D}{\text{P.E.}_D}$	1.13				3.87				.61			

In the Control Series, with normal subjects attempting to inhibit pain reactions when the left leg was stimulated, there is no difference between the two legs. Although preliminary experimentation showed that this flinch can be voluntarily inhibited, it was not governed in that way by these subjects under the control conditions. It is possible that if attention had been called to that particular feature of behavior the results would have been different.

2. *Respiratory Oscillation.*—Two types of measurement were used on the respiratory tracings. The first is, in effect, a measurement of the *amount of breathing.* It requires use of the Hull oscillometer (**5**), an instrument which summates the vertical oscillations of a wavy line. An inch of vertical movement on a record is equal to 39 oscillometer units. In a pneumographic tracing, this summation of vertical movements is a measure of the total amount of respiratory activity.

Intervals of 20 secs. duration were measured off before and after the stimulus (see Fig. 3, *T* and *T'*). Total amount of vertical oscillation during each of these two periods was measured. The amount in the pre-stimulus period was subtracted algebraically from the amount in the post-stimulus period. The algebraic remainder indicates the *change* in amount of breathing which follows stimulation.

Table 2 shows the median amount of pre-stimulus oscillation for each subject under the three experimental conditions. In order to economize space, the post-stimulus period has been omitted. The columns labelled 'median difference' give the algebraic difference between the pre- and post-stimulus periods. The median post-stimulus amount of oscillation for each subject may be determined by adding algebraically the figure given in the 'median before stim.' column to the one given in 'median difference' column.

The median differences between pre- and post-stimulus oscillation have been averaged for the seven subjects (see row labelled 'mean of medians'). It will be seen that for stimulation of the right leg in the Waking Series the mean pre-stimulus oscillation for all subjects is 275.1 oscillometer units.

TABLE 2

Respiratory Oscillation

Showing in parallel columns, for each leg under three experimental conditions, the median amount of oscillation in respiratory tracings during a 20-sec. pre-stimulus period, with median difference, whether increase (+) or decrease (−), between this amount and the amount found in a comparable post-stimulus period (to economize space the post-stimulus period is not given in this table). At the bottom are given means of medians in oscillometer units, P.E.$_M$'s, differences between the two legs, and P.E. of these differences. Number of stimulations represented by each median may be found in Table 1; see columns captioned 'No. of stims.'

Subject	Waking Series				Trance Series				Control Series			
	Right Leg		Left Leg		Normal Leg		Anesth. Leg		Normal Leg		Vol. Inhib.	
	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference
Cl.	197	+14	201	− 4	219	+ 5	219	− 6	231	+ 1	262	−34
Co.	176	+ 7	158	+ 9	165	+ 31	182	+32	186	+ 7	198	+18
L.	322	+34	307	+33	263	+ 51	261	−22	438	+43	514	− 7
M.	205	+79	231	+22	301	+ 24	245	+54				
S.	299	− 9	325	+ 6	379	+ 4	356	+23	388	−22	344	+41
Ta.	450	+59	534	+99	447	+109	462	−29	321	+57	307	+91
Tr.	277	+41	246	+21	363	− 7	326	−62	317	+51	308	+53
Mean of medians.	275.1	+32.1	286.0	+26.6	305.3	+ 31.0	293.0	− 1.4	313.5	+26.2	322.2	+27.0
P.E.$_M$.		7.26		8.06		9.33		9.47		6.78		11.20
Difference between legs.	5.5±6.93				32.4±6.23				.8±8.09			
$\frac{D}{\text{P.E.}_D}$	.79				5.20				.10			

After stimulation there is a mean increase of 32.1 units. The P.E. of this difference is 7.26. The change in amount of respiratory oscillation following painful stimulation is, therefore, over 4 times the P.E. of the difference and we may conclude that this type of measurement gives a reliable index of physiological reaction to cutaneous pain.

The difference between the means for the two legs in the Waking Series is 5.5 oscillometer units with a P.E. greater than the difference itself. The two legs are approximately

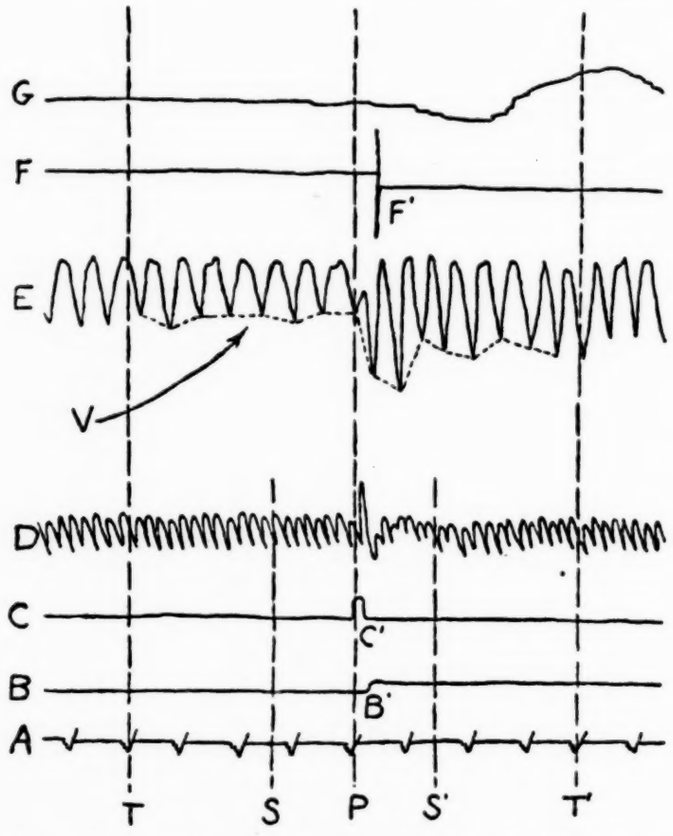

FIG. 3. Reproduction of typical record. (*A*) 5-sec. time intervals; (*B*) facial grimace tracing; (*B'*) record of flinch; (*C*) pain stimulus tracing; (*C'*) stimulus; (*D*) pulse tracing; (*E*) respiratory tracing; (*F*) leg withdrawal reflex tracing; (*F'*) leg flinch; (*G*) galvanic skin reaction tracing; (*T*) beginning of 20-sec. pre-stimulus period; (*S*) beginning of 7½-sec. pre-stimulus period; (*P*) pain stimulus; (*S'*) end of 7½-sec. post-stimulus period; (*T'*) end of 20-sec. post-stimulus period; (*V*) line followed by oscillometer in measuring variability in depth of inspirations.

equal in sensitivity, then, as measured by this response to pain.

In the Trance Series, however, the left leg is suggested anesthetic and the size of the mean indicates that no changes

in breathing are apparent when that leg is stimulated. The right leg retains its normal capacity for reaction. The difference between the legs is 5.2 times the P.E.$_D$, indicating that there are 1999 chances in 2000 that hypnotic anesthesia would produce a similar diminution in the degree of increased oscillation normally following pain stimulation if these measurements were repeated on other subjects.

In the Control Series, the means for the two legs are almost exactly the same. Both show the typical reaction qualitatively and quantitatively that they showed in the Waking Series. The respiratory reaction to painful stimuli given under hypnotically suggested anesthesia cannot be voluntarily simulated under these conditions.

3. *Respiratory Variability.*—The following method of measuring changes in respiratory activity caused by painful stimulation was devised by Professor Clark L. Hull.

It will be seen from Fig. 3 that in a series of inspirations following a pain stimulation the depth of the individual inspirations varies to a much greater extent than before stimulation. The measurement of this difference is, of course, a measure of physiological variability and has nothing to do with the statistical value 'mean variation.'

Measurement of the variability was made with the oscillometer. A transparent millimeter scale might be used with almost equal accuracy. The total amount of vertical difference between the depth of the several inspirations is measured during 20-sec. periods before and after stimulation. In Fig. 3, for instance, the oscillometer is moved along the dotted line (V) and differences in depth of the various inspirations, reading from left to right in consecutive order, are summated.

This sum is divided by $N - 1$, where N equals the number of inspirations measured. The result of this computation is the average difference between the depths of the various inspirations. This formula $\left(\frac{V}{N-1}\right)$ puts on a comparable basis the variability of breathing for any two periods which contain an unequal number of breaths.

TABLE 3

Respiratory Variability

Showing in parallel columns, for each leg under three experimental conditions, the median amount of variability (see text, p. 13) in respiratory tracings during a 20-sec. pre-stimulus period, with median difference, whether increase (+) or decrease (−), between this amount and the amount found in a comparable post-stimulus period. At the bottom are given means of the medians in oscillometer units, P.E.$_M$'s, differences between the two legs, and P.E. of these differences.

Subject	Waking Series				Trance Series				Control Series			
	Right Leg		Left Leg		Normal Leg		Anesth. Leg		Normal Leg		Vol. Inhib.	
	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference
Cl	1.3	+ .1	2.0	− .4	2.8	−1.4	3.8	−1.8	3.2	− .9	3.1	+1.7
Co	.6	− .2	.5	+ .2	1.1	+ .3	1.2	− .1	.6	+ .3	1.0	− .4
L	2.1	+6.9	1.0	+3.7	1.5	+4.8	2.0	− .3	6.5	+1.5	6.6	+1.5
M	2.3	+5.1	4.2	+4.0	3.6	+3.6	4.2	− .3	—	—	—	—
S	4.6	−1.3	5.1	−2.6	1.9	+ .8	1.7	+ .2	2.2	+4.7	2.8	+ .4
Ta	1.1	+1.2	2.4	+2.0	1.3	+2.0	2.1	− .1	1.1	+1.2	1.4	+3.1
Tr	3.6	+ .1	4.3	+3.5	6.3	+2.9	5.4	+1.2	2.1	+1.3	2.2	+1.2
Mean of medians	2.23	+1.70	2.79	+1.49	2.64	+1.86	2.91	− .17	2.62	+1.35	2.85	+1.25
P.E.$_M$		.72		.59		.67		.21		.52		.30
Difference between legs	.21±.50				2.03±.56				.10±.54			
$\frac{D}{\text{P.E.}_D}$	.42				3.62				.18			

That it has proven to be a reliable measurement of reaction may be seen from Table 3. On both legs, in the Waking Series, the differences between the amount of variability before and after stimulation are over twice their P.E.'s and approximately the same ratio obtains for the normal leg in the Trance Series.

The data from this measurement have been treated statistically in the same way as the data concerning total respiratory oscillation.

It should be noted that the difference between the right and left legs in the Waking Series is only .42 $P.E._D$. The difference between the normal and anesthetic legs in the Trance Series, however, is 3.62 $P.E._D$. We may conclude that the anesthesia practically eliminates the increased-variability response to pain, since on that leg the increase in post-stimulus variability is almost nil. It is an interesting fact that this respiratory variability is the only one of the seven psycho-physiological measurements which shows no reversals among the seven subjects.

The Control Series shows no difference between the two legs.

4. *Pulse Oscillation.*—Periods of $7\frac{1}{2}$ secs. duration before and after the stimulus were marked off on the sphygmograph tracing. Measurement of the vertical oscillation was made with the oscillometer. It was hoped that this type of measurement would give a reliable quantitative index for the sometimes observable diminution in pulse amplitude following painful stimulation. This reaction is quite characteristic for some subjects, but seems never to occur at all in others (see Fig. 3, tracing *D* after stimulus).

The treatment of the data and construction of the table (Table 4) are the same as were described for the 'respiratory oscillation' reaction and Table 2. In the pulse data, however, there is an extreme variability not only between subjects but within the behavior of any one subject. It will be seen that the median reactions of the right and left legs for any one subject are very unequal even in the Waking Series.

The mean reaction for all subjects is in no case a statistic-

TABLE 4

Pulse Oscillation

Showing in parallel columns, for each leg under three experimental conditions, the median amount of oscillation in pulse tracings during a 7½-sec. pre-stimulus period, with median difference, whether increase (+) or decrease (−), between this amount and the amount found in a comparable post-stimulus period. At the bottom are given means of medians in oscillometer units, P.E.$_M$'s, differences between the two legs, and P.E. of these differences.

Subject	Waking Series				Trance Series				Control Series			
	Right Leg		Left Leg		Normal Leg		Anesth. Leg		Normal Leg		Vol. Inhib.	
	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference
Cl	119	− 3	125	−18	118	+11	124	+ 9	152	−10	143	−5
Co	94	+ 1	94	+11	107	− 3	102	− 7	40	+ 1	39	+1
L	163	−12	163	−24	117	−40	145	− 5	81	0	84	−3
M	73	+25	80	− 2	97	− 3	91	−23	—	—	—	—
S	56	+14	57	+ 3	96	− 1	81	+ 7	116	− 9	115	−1
Ta	93	−28	125	− 8	147	−32	144	0	100	− 7	100	−6
Tr	172	+ 6	161	+ 7	197	− 5	197	+ 2	159	+ 3	154	+5
Mean of medians	110.0	+ .43	115.0	− 4.43	125.6	−10.43	127.3	− 2.43	108.0	− 3.67	105.8	−1.50
P.E.$_M$		4.08		3.06		4.34		2.54		1.42		1.03
Difference between legs	4.86±3.55				8.00±4.59				2.17±.93			
$\frac{D}{\text{P.E.}_D}$	1.37				1.74				2.33			

ally reliable difference between pre- and post-stimulus pulse oscillation. The differences between the two legs under any experimental condition are of course meaningless in view of this unreliability.

5. *Pulse Variability.*—The technique of measurement and statistical treatment of data are the same as were described for respiratory variability.

This type of measurement constitutes another attempt to find a way of measuring the pulse phenomenon described above. It has been successful, apparently, for in the Waking Series the two legs are approximately equal in their tendencies to cause variability in pulse activity, and the means of the columns of differences are from 3.5 to 5 times the size of their P.E.'s.

In the Trance Series, with left leg anesthetic, the variability is greatly decreased though not entirely obliterated, following stimulation of the left leg. The difference is 3.04 $P.E._D$.

The Control Series includes data from only 4 subjects because damage to the sphygmograph made pulse tracings too small to be measured for variability. The difference here is insignificant.

6. *Galvanic Skin Reaction.*—Following a painful stimulation there is a characteristic 'dip' or deflection in the tracing taken from the galvanometer. The latency of this reaction varies between 2 and 7 seconds, but without exception there is a return to normal in less than 20 seconds total elapsed time after the stimulation (see Fig. 3, *G*).

The amount of deflection during the 20 sec. post-stimulus period was measured with the oscillometer and compared with the amount of normal galvanometric drift found in a similar pre-stimulus period. The difference between these two values constitutes the galvanic skin reaction to cutaneous pain stated in quantitative terms.

In Table 6 will be found the median pre-stimulus drift for each leg under each of the three experimental conditions, and the difference between that value and the amount of post-stimulus deflection. In the Waking Series the mean

TABLE 5

Pulse Variability

Showing in parallel columns, for each leg under three experimental conditions, the median amount of variability (see text, p. 17) in pulse tracings during a 7½-sec. pre-stimulus period, with median difference, whether increase (+) or decrease (−), between this amount and the amount found in a comparable post-stimulus period. At the bottom are given means of the medians in oscillometer units, P.E.$_M$'s, differences between the two legs, and P.E. of these differences.

Subject	Waking Series				Trance Series				Control Series			
	Right Leg		Left Leg		Normal Leg		Anesth. Leg		Normal Leg		Vol. Inhib.	
	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference
Cl.	.4	0	.4	0	.4	+.1	.4	0	.1	0	0	0
Co.	.4	+.2	.4	+ .2	.4	+.3	.4	+.3	—	—	—	—
L.	.6	+.5	.6	+1.0	.6	+.4	.6	+.4	—	—	—	—
M.	.6	+.8	.7	+1.2	.6	+.7	.6	+.2	—	—	—	—
S.	.9	0	1.1	− .5	.7	+.3	.8	−.1	.3	+.1	.2	+.1
Ta.	.9	+.7	1.2	+1.4	.9	+.3	1.0	0	.3	+.2	.2	+.4
Tr.	.5	+.2	.7	+ .3	.8	−.1	.7	+.2	.3	+.1	.2	+.3
Mean of medians	.614	+.343	.729	+ .514	.629	+.286	.643	+.143	.250	+.10	.15	+.15
P.E.$_M$		.077		.165		.058		.043		.024		.069
Difference between legs	.171±.09				.143±.047				.050±.046			
$\frac{D}{\text{P.E.}_D}$	1.90				3.04				1.08			

deflection is 11.0 oscillometer units for the right leg and 11.43 units for the left. The P.E.'s of these differences are 2.93 and 4.36 respectively, indicating that these are valid measures of galvanometric deflection to painful stimulation.

The differences between the two legs under the three conditions are interesting. There is very close equilibration in the Waking Series; the critical ratio is only .14. But in the Trance Series, the anesthetic leg produced a considerably modified reaction to stimulation. There is no question as to whether there was a reaction, but the difference between its size and the size of the reaction from the normal leg is rather marked (**7, 10**). The critical ratio of the difference is 2.95. This leads us to conclude that hypnotic anesthesia can modify the reactions of the autonomic as well as the central nervous system to painful stimulation.

There was no modification of the galvanic reaction in the Control Series. Voluntary inhibition did not affect its activity.

7. *Comparison of Reactions in Trance and Waking States.*— For a long time there has been some question as to whether the trance state itself, without any specific suggestion of change in cutaneous sensitivity, modifies normal reactions to stimuli. To throw light on this matter, a comparison has been made of the reactions to pain stimuli given on the right leg in the waking series and on the normal (right) leg in the trance series. The P.E.'s of the differences between the mean reactions of these two sets of data have been computed for five of the six measurements of reaction. The pulse oscillation was not compared since it has shown itself to be a non-significant measurement.

The percent of difference and the critical ratios $\left(\frac{D}{\text{P.E.}_D}\right)$ of the differences between mean reactions derived from comparable legs under trance and waking conditions are as follows:

Facial grimace	− 43.32%	3.97
Respiratory oscillation	− 3.43	.13
Respiratory variability	+ 9.41	.42
Pulse variability	− 16.61	1.58
Galvanic skin reaction	− 28.63	1.18

TABLE 6

Galvanic Skin Reaction—Oscillation

Showing in parallel columns, for each leg under three experimental conditions, the median amount of oscillation in galvanic tracings during a 20-sec. pre-stimulus period, with median difference, whether increase (+) or decrease (−), between this amount and the amount found in a comparable post-stimulus period. At the bottom are given means of the medians in oscillometer units, P.E.$_M$'s, differences between the two legs, and P.E. of these differences.

Subject	Waking Series				Trance Series				Control Series			
	Right Leg		Left Leg		Normal Leg		Anesth. Leg		Normal Leg		Vol. Inhib.	
	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference	Median Before Stim.	Median Difference
Cl.	9	+ 6	7	+ 8	5	+10	7	+ 5	4	+ 5	5	+ 4
Co.	1	+12	3	+ 7	3	+ 3	2	+ 3	2	+ 5	2	+ 4
L.	2	+ 3	2	+ 2	2	+ 3	2	+ 2	2	+ 1	3	− 1
M.	5	+16	7	+10	6	+16	4	+11	—	—	—	—
S.	8	+ 5	11	+ 5	6	+ 3	3	+ 3	7	+ 8	6	+ 9
Ta.	11	+ 4	13	− 4	7	+10	7	+10	0	+ 5	7	+ 8
Tr.	15	+31	13	+52	7	+10	7	+ 9	10	+21	17	+22
Mean of medians	7.28	+11.0	8.0	+11.43	5.14	+ 7.85	4.57	+ 6.14	5.67	+ 7.50	6.67	+ 7.67
P.E.$_M$		2.93		4.36		1.18		.89		1.75		2.0
Difference between legs	.43±3.09				1.71±.58				.17±.41			
$\frac{D}{\text{P.E.}_D}$	.14				2.95				.41			

From this it will be seen that the trance state reduces to a very great extent the number of facial grimace reactions to pain. This is not unexpected, for the hypnotic trance, as it was induced for this experiment, is a state of extreme quiescence which apparently reduces superficial body movements. The other four measurements show no reliable differences between waking and trance reactions, but the fact that three of the four differences indicate a somewhat lessened reaction in the trance is probably not without significance. It may be that induction of anesthesia on the left leg during the trance is not completely differential; *i.e.*, there may be a faint 'spread' of decreased sensitivity throughout the organism.

Incidental Observations

1. *Differential Anesthesia of the Temperature Senses.*—The subject (Co) was put into a trance and instructed that he would have post-hypnotic anesthesia for burning heat but that he would be able to feel and recognize a cold stimulus with his normal acuity. He was awakened and a piece of ice, shielded from his sight with a handkerchief, was applied to the part of his leg which had been affected by suggestion. He immediately reported that he felt something cold, like ice. When a burning hot piece of metal was applied to the same spot and the flesh allowed to sear slightly, he felt nothing. The process was repeated and, although the subject saw the metal heated over a flame, there was no verbal or other obvious response to heat or pain. Cold sensitivity was normal throughout.

2. *Proprioceptive Anesthesia.*—The subject (L) was put into a trance and anesthesia of the proprioceptors of the left leg was induced. The suggestion given was, "You will not be able to tell where your left leg is." That leg was then laid across a chair higher than the footstool used in the regular experimental procedure. L reported that he was unable to locate the leg. When he was ordered to locate it with his hand, he searched first at the level of the footstool.

Summary

1. The modifying effects of hypnotic anesthesia on normal pain reactions at four psycho-physiological levels of behavior have been studied experimentally on seven subjects.

2. Results indicate that the facial flinch and the increased oscillation and variability in the respiratory tracing are practically eliminated by this type of anesthesia.

3. Suggested anesthesia reduces to a considerable extent the increased variability which is characteristically found in the pulse tracing following a painful stimulation.

4. The galvanic skin reaction shows a mean reduction of 20 percent on the anesthetic leg. This probably indicates a modification of the reaction, but further evidence will be required to verify this supposition.

5. A series of stimulations was given in which the subject was instructed to inhibit his reactions to pain when the left leg was stimulated. None of the reactions measured showed modification to any statistically reliable extent.

That hypnotic anesthesia is in any sense a conscious simulation seems doubtful. Voluntary inhibition of reaction to pain does not present a picture even remotely resembling the reaction under true hypnotic anesthesia.

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TRANSFER OF FATIGUE AND IDENTICAL ELEMENTS

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Transfer of fatigue in mental work is a well recognized concept. It is given precise formulation in Robinson's (7) seventh principle of work decrement, to the effect that—"The work decrement of a given *S–R* connection is relative to the decrements which have developed in other *S–R* connections." Yet the experimental basis for the concept is meagre; the published studies can be counted on the fingers of one hand. Chapman (4) obtained a lower objective level of performance in transferring his subjects from arithmetic to cancellation and vice versa than was obtained from transferring them from a resting state to arithmetic. Arai (1) found that she displayed less efficiency in mental multiplication after having previously translated one of Dewey's essays into Japanese, than she did after having previously rested. Ash (2) noticed a transfer of fatigue from adding to the control of reversible perspective. Berliner (3) discovered that the fatigue developing from a normal day's mental work affected the ability of her subjects to control their imagery at the end of the day. Fernberger (5), however, found that the translation of difficult German for a half hour had no such effect on the accuracy of lifted weights judgments as did work done with the muscles used in judging. In general, then, it is admitted that there is a transfer of some of the decrement developed in one mental task to the performance of another subsequent one. And it is also recognized that the amount of transfer obtaining between mental tasks is considerably greater than that between muscular operations,

when the relative dissimilarity of the operations is held constant as the nature of the comparison admits.

But there is practically nothing known definitely about the precise conditions under which transfer will take place; and less is known about the factors determining the degree which will appear, and how this is related to the nature of the tasks between which transfer occurs.

There are roughly two current theories about it: the 'common elements' theory and the 'difficulty' theory. The latter assumes that the harder the first task, the more fatigue will be carried over from it to the second task. But as Robinson (7) pointed out, we have no good criterion of difficulty of a mental task which is not itself dependent upon some such factor as time or errors, or worse yet, is measured by the amount of transfer which does actually occur, thus begging the question. The second theory is a corollary of the law of transfer of training. It has been argued that this theory also begs the question at issue, because the criterion of 'common' is the fact of transferability. Now this may be true where an attempt has been made to analyse the transfer pertaining between, say, German translation and judgments of weights. But, isn't it possible to substitute the word 'identical' for 'common' and insist that the two tasks be compared only on the basis of the number of identical elements in the two? Stated in this way, the theory seems at least capable of experimental verification, even though such verification has not been made heretofore.

The present study is an attempt to experimentally test this hypothesis: that fatigue transfer is proportional to the number of identical elements in the two tasks between which the transfer occurs. There is no intention of suggesting that the identical elements hypothesis exhausts the explanatory possibilities. Lashley has suggested that there might develop a fatigue of the central facilitative mechanism which corresponds to the traditional principle of 'attention'; but, since this central facilitation is present in more or less degree in *all* mental work, it may itself be considered a 'common element' to all tasks.

A general criticism of the previous attempts to determine a relation between fatigue transfer and the similarity of the two tasks is that the kinds of work chosen differed from one another in no quantitative way. Thus, in Chapman's study of transfer from addition to cancellation, who is to say how many degrees of difference there are between adding and cancelling as compared with adding and translating German or even resting? Hence, whatever results are found empirically, they cannot be interpreted in terms of degrees of similarity. In choosing a set of tasks for the present experiment, an attempt was made to meet this objection by selecting a series of similar operations, the degree of similarity between which can be quantitatively stated.

Experiment I

Plan of the Experiment

The task used was the continuous writing of alphabetical sequences. It has the advantage of being articulated into small comparable units, and permits of the selection of a series of distinct work sequences, the quantitative similarity between which can be systematically varied. Thus the series *abcabcabcabc* may be compared with the series *abdabdabdabd* which has *one* element of difference from it, or with the series *afeafeafeafe* which contains *two* new elements, or with *defdefdefdef* in which every element is new. Now if our hypothesis is correct, we ought to find the greatest degree of fatigue transfer between the writing of *abcabcabcabc* and the subsequent writing of *abcabcabcabc*, etc. We should find less between the writing of *abdabdabd*, etc., and the subsequent writing of *abcabcabc*; still less between *afeafeafe*, etc., and *abcabcabc*; and least between *defdefdef* and *abcabcabc*. Therefore, the following series of conditions was arranged. In

		Constant Task	Alternate Task
Cond. I...	*All* elements common.....	Write abcabc, etc.	Write abcabc, etc.
Cond. II..	*Two* elements common....	Write abcabc, etc.	Write abdabd, etc.
Cond. III.	*One* element common.....	Write abcabc, etc.	Write afeafe, etc.
Cond. IV.	*No* elements common.....	Write abcabc, etc.	Write defdef, etc.
Cond. V..	Control condition.....	Write abcabc, etc.	Rest

every condition, the subjects worked one minute on the control task, then one minute on the alternate task, then one minute on the control, etc., thus alternating tasks for sixteen minutes. The result was a cumulative fatigue effect, the amount of which would depend on the similarity of the two tasks.

Twenty subjects, all graduate students in Psychology, went through all five of the conditions three separate times. Hereafter, one complete taking of all five conditions by the twenty subjects will be spoken of as a Cycle. There were, then, three distinct cycles of the experiment.

The subjects were divided into five groups. In Cycle I, each group went through the conditions in a different order. Group I took them in the order I, II, III, IV, V, whereas Group II took them in the order II, III, IV, V, I, etc. In this way, no condition received the benefit of more practice than another, in the final averaging. The conditions were taken at least a day apart. In Cycle II, the order of taking the conditions was reversed for each group, in order that practice effects might be still further eliminated in the final averaging.

The procedure was as follows: The subject was supplied with a standard pencil, and sheets of standard writing paper. He was instructed to write as rapidly as possible without making errors; errors to be corrected if made. The experimenter marked the passage of time by tapping on the table every quarter minute, whereupon the subject made a vertical mark at the point where he was writing, thus marking off his work into quarter-minute units, on the basis of which his accomplishment by quarter minutes could later be computed. At the end of each minute, the experimenter said 'Change!' The subject shifted immediately to the other task. At the end of sixteen minutes, the subject was told to stop.

This first experiment covered a period somewhat less than two months.

Results of Experiment I

The results can be treated in at least two ways. One method would be to compute the total amount of work done

during the minutes in which the subject was working on the constant or standard task, *i.e. abcabcabc*, in each of the five conditions, and compare the five conditions with respect to this factor. This would show us the average level of performance on the standard task, when that task is alternated with tasks of differing degrees of similarity to it. Another method would be to construct work curves for the standard task, one for each condition. This could be done by taking minutes 1, 3, 5, 7, 9, 11, 13, and 15, in which the standard task was performed, and plotting the level of performance in these successive periods. We could then compare the decrements developed in the work curves for the different conditions. Presumably the condition in which the alternate task was most dissimilar to the standard task would give a work curve with the least decrement.

First Method.—The total number of letter groups written in the standard task, for each of the five conditions, is given in Table 1.

TABLE 1

TOTAL ABC UNITS WRITTEN

Cycle	Cond. I	Cond. II	Cond. III	Cond. IV	Cond. V
I	6508	7280	7516	7934	8138
II	8304	8360	8552	8782	8855
III	8922	9115	9142	9110	9275
Average	7911	8252	8403	8609	8756

Some interesting facts are brought out by these figures. First, they show a rather regular relation between amount of work done and similarity of the alternate to the standard task. The greater the similarity, *i.e.*, the more identical elements, the lower the resulting level of performance on the standard task. This seems to substantiate the hypothesis on which the investigation started. Secondly, there is no greater jump in level of performance from the condition with no common elements to that with *rest*, than between any other pair of adjacent conditions in the series. A third feature of importance is that the three cycles of the experiment all show the same general tendency, and we may conclude from that,

that practice has not distorted the data to any important degree.

Second Method.—In Table 2 are shown the numerical decrements for each of the five conditions for all three cycles. In Fig. 1, the work curves for the five conditions have been plotted. The relative decrements developing in the different conditions, in the case of the standard task, can be directly compared. The decrements are computed by subtracting the work done during the first four odd minutes from that done during the last four odd minutes.

TABLE 2

DECREMENTS RESULTING FROM THE DIFFERENT CONDITIONS

Cycle	Cond. I	Cond. II	Cond. III	Cond. IV	Cond. V
I	−176	− 66	−31	+23	+75
II	−152	−140	−61	−39	+40
III	−225	−100	−65	−55	+75
Average	−185	−102	−52	−24	+63

Since these results are cumulative, they are subject to a different interpretation from those of Table 1. They might be spoken of as cumulative fatigue transfer effects. At any rate, they seem to follow a definite trend. The amount of decrement developing in the writing of the *abc* sequence is plainly a function of the similarity of the alternate task to it; *i.e.*, the number of common elements in the two situations. In Fig. 1, below, the five work curves are plotted as from a common origin.

The curves, since they are plotted from a common origin, give a direct basis for comparison of the relative decrements in the various conditions. The points are averages, not totals, so that they express the amount done per minute by the average subject for the eight successive odd minutes of work. It is at once apparent that initial decrements occur in every condition except Condition V, which shows a rise from the very start. This is the condition in which rest is alternated with the work, thus giving a discontinuity to the work. This very discontinuity of work has been shown by Robinson and

Heron (**8**) to be the necessary condition for the appearance of the phenomenon of warming-up in work curves, so apparently the steady rise in the curve of Condition V is warming-up.

A method of checking the validity of the preceding curves for the standard task, as affected by the alternate tasks of

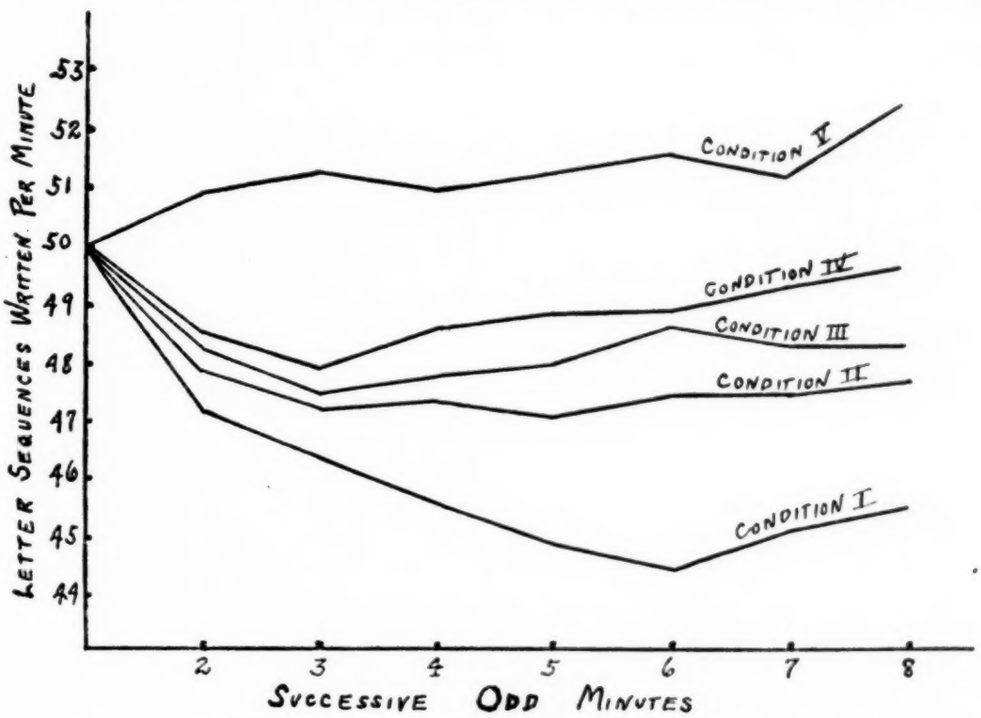

FIG. 1. The standard task. Average work curves for each condition.

differing similarity to it, would be to plot the curves for the varied tasks for each condition. Theoretically they ought to show the same relationship of progressively greater decrement with progressively greater similarity to the standard task with which they were alternated. This can be done by selecting the work done in the even minutes, 2, 4, 6, 8, 10, 12, 14, and 16, and plotting the work curves of each condition. Figure 2 shows the results. It is evident that the same tendency toward a correlation between similarity and decrement is present here. The validity of the principle is thereby strengthened.

It was stated, in describing the method of marking off time units during the work, that a signal was given every quarter-minute. As a result, it is possible to determine the course of efficiency during each minute, by plotting the four

points representing the four quarter-minutes in each case. The resulting short work curves will show in what way the fatigue transfer takes place from one minute to the following one. Does it show up most at first, immediately after the shift of task, or does it come on gradually during the minute? Is there any constancy about it? Does it differ for the different conditions in any systematic way, and especially

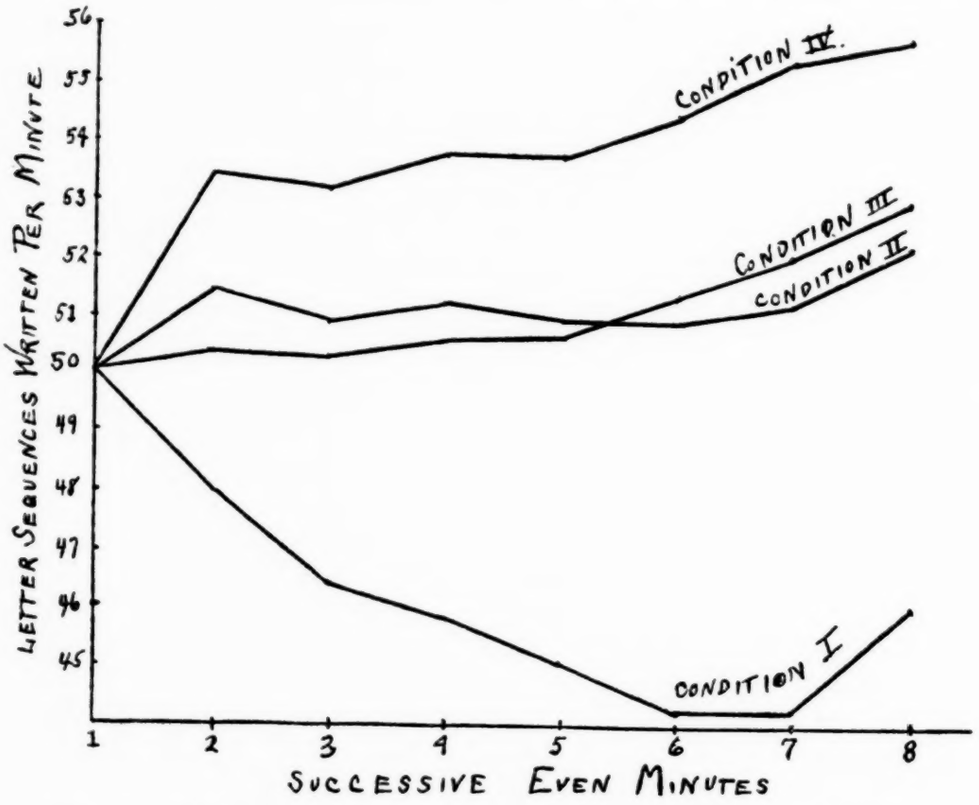

FIG. 2. The alternate tasks. Average work curves for each condition.

for the conditions involving rests in alternate minutes? These questions can be most easily answered by showing the average minute's work curve for each condition, for the standard task. The curves for the alternate task agree with these very closely. Upon these curves we have superimposed an average *first* minute curve, which naturally shows a large initial spurt, being the first minute of work.

An examination of the Figure shows at once how the conditions differ. The fewer the identical elements in the preceding task, the greater will the initial spurt be at the beginning of the minute. When rest preceded, the initial spurt in

the minute is as great as the initial spurt in the work curve itself. Compare Condition V with the curve for the initial minute of work.

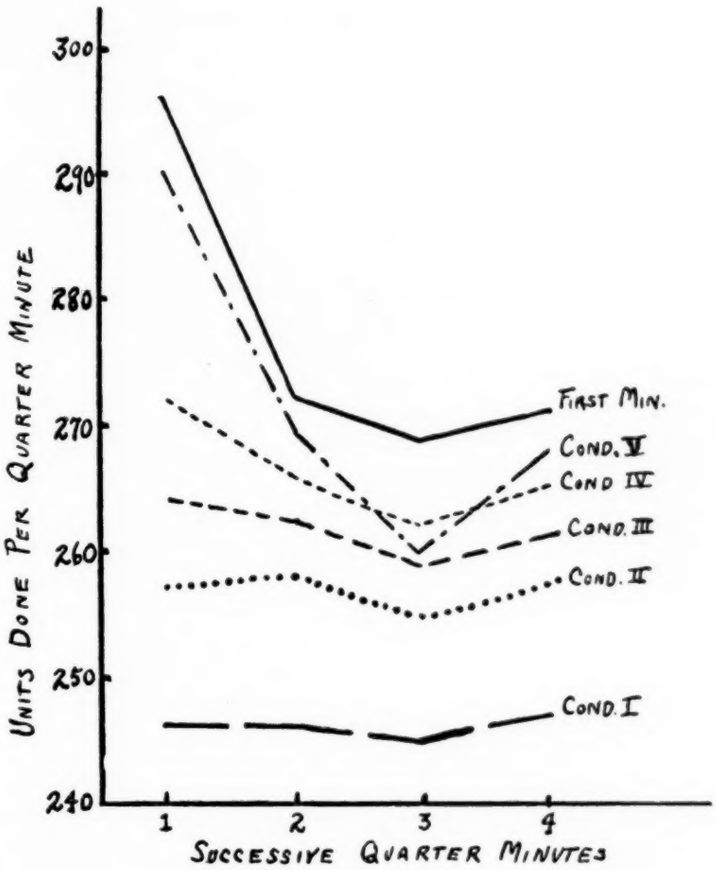

FIG. 3. Minute curves for standard task.

Conclusions from Experiment I

From the foregoing results, the following general principles may be deduced:

1. In transferring from one type of work to another type, there will be a tendency for the level of performance in the second task to be detrimentally affected in proportion to the number of identical elements in the two tasks.

2. In alternately working on two tasks, there will be a tendency for the decrement developing in both tasks to be proportional to the number of elements common to both.

Experiment II

Plan of the Experiment

The purpose of the second experiment was to determine whether any type of task could be found in which the principle of Experiment I would not operate; *i.e.*, where increasing dissimilarity would not lessen, but would rather increase the amount of fatigue transfer or interference in the alternate performance of the two tasks. The intention was not to duplicate such a situation as that used in the experiment of Jersild (**6**) on mental set and shift, where the shifts between the two operations were so rapid as to cause a constant conflict, but rather to preserve the same time relations as before, working at each task an appreciable time before changing. The point at issue was this: if increasing dissimilarity reduces the fatigue transfer between two operations, will this be true if dissimilarity takes the form of oppositeness or antagonism? May there not be dissimilar elements whose very antagonism would prove more productive of fatigue transfer between one another than if they were identical?

Obviously, there is no good logical criterion of oppositeness or antagonism between elements; but it is easy to test for antagonism empirically. It can be found right within the letter writing situation. A series of tests was made of various pairs of letters to find which ones have the highest degree of antagonism. Naturally it is impossible to insure that letters in combinations such as were here used will behave as they do in isolation. The configuration problem enters here. Yet the fundamental assumptions of this whole study ignore the configuration problem, not because of failure to recognize its importance, but because it is felt that, if there is any truth in the hypothesis of identical elements, it will come out in spite of the disturbing effect of configurations. And what is to be gained by still further complicating the interpretation?

Tests showed a high degree of conflict between q, p, g, and z, when these are written as small letters. Also n and v conflict. These letters were therefore chosen. Perhaps they are not the most conflicting elements that could be found, but they serve the purposes of the experiment.

Four conditions were finally arranged, involving all degrees of conflict, from no antagonistic elements to three such elements. The elements in the two tasks which did not conflict were identical. Hence an opportunity was given to test the relative strength of identity versus antagonism in producing fatigue transfer. The 'rest' condition was omitted.

Cond.		Constant Task	Alternate Task
I	*All* elements *common*.....	Write npznpz, etc.	Write npznpz, etc.
II	*One antag.* element.....	Write npznpz, etc.	Write nqznqz, etc.
III	*Two antag.* elements.....	Write npznpz, etc.	Write ngqngq, etc.
IV	*Three antag.* elements.....	Write npznpz, etc.	Write vgqvgq, etc.

Nineteen subjects took part, but the records on only sixteen were used, three being incomplete. The method of equating practice effect was similar to that of Experiment I. Two cycles were run, and in addition a practice cycle. Each group of four subjects went through the conditions in a different order. All the subjects took Cycle II in the reverse order from Cycle I. The length of the work period was again 16 minutes, but the shifts occurred every one-half minute, in order to give the principle of antagonism every opportunity to work. A further change was the placing of the alternate task in the odd one-half minutes and the standard task in the even one-half minutes, so that from the very first the effect of the alternate task would show upon the level of performance in the standard task, *i.e.* even in the second one-half minute.

Results of Experiment II

The results can again be treated in two ways. The total work done on the constant task can be compared for the various conditions. And, secondly, the decrements in the work curves for the various conditions can be compared.

First Method.—The total number of letters written in the standard task, for each of the five conditions, is given in Table 3.

An examination of the Table shows at once that the principle of identity has operated in spite of the antagonism.

TABLE 3

TOTAL NPZ LETTERS WRITTEN

Cycle	Cond. I	Cond. II	Cond. III	Cond. IV
I	10640	10859	11079	11006
II	12186	12225	12315	12361
Average	11413	11542	11697	11684

Just as in Experiment I, there is a progressive increase in amount done with progressive decrease in the number of identical elements in the alternate task. It is possible that the antagonism of opposed elements has cut down the benefit of dissimilarity somewhat, but it has not disturbed the general trend.

Second Method.—The numerical decrements in the work curves of the standard task, for each of the four conditions, for both cycles, are shown in Table 4.

TABLE 4

DECREMENTS RESULTING FROM THE DIFFERENT CONDITIONS

Cycle	Cond. I	Cond. II	Cond. III	Cond. IV
I	−84	+25	+75	+84
II	−92	+23	−21	−69
Average	−88	+24	+27	+ 7.5

Cycle I demonstrates the same trend as that shown in Table 2 of Experiment I. There is a progressive decrease in decrement with increase in dissimilarity, despite the increased antagonism of conflicting elements which this presumably involves. Cycle II however introduces a disturbing reversal of order which throws Condition IV out of line in the final averages.

A method of checking on the results is to compare with these the decrements which developed in the work curves of the alternate tasks in each of the four conditions. They are shown in Table 5.

Here the trend is consistent throughout and confirms the conclusion from Table 4, that the principle of identity operates in spite of the presence of conflict.

TABLE 5

DECREMENTS IN THE ALTERNATE TASKS

Cycle	Cond. I	Cond. II	Cond. III	Cond. IV
I	− 97	+30	+45	+165
II	−173	−14	− 9	+ 33
Average	−135	+ 8	+18	+ 99

GENERAL CONCLUSIONS

The results of the two experiments may now be summarized in the form of two general principles of fatigue transfer:

1. In alternating between two tasks, the general level of performance in each task, as well as the fatigue decrement developing in each task, will be proportional to the number of identical elements in the two tasks.

2. The foregoing principle operates even when the reduction in number of identical elements involves the substitution of more and more antagonistic or conflicting elements.

DISCUSSION

The term 'element' has been used here in a rather special sense which might easily cause ambiguity of meaning if interpreted indiscriminately. In fact, it has probably been used in a way which would be inacceptable to those who have promulgated the doctrine of identical elements in other fields such as learning. But, either the term is or is not capable of exact quantitative definition. If not, then it is mere tautology and not worthy of the term theory. Now, obviously, we can say nothing at all concerning the neural elements involved, whether they are identical or not. Hence the term 'element' cannot mean neural element. And all that is left for it to mean is 'elements in the stimulus response situation.' But it is almost impossible to identify the number of identical elements in two stimulus-response situations *psychologically defined.* And the Configurationist will hasten to assure us that identical elements are not identical in two different settings anyway. So we are bound, if we use the concept of identical elements at all, to resort to a *logical* use of the

term. It is possible to select logically identical elements in two stimulus-response situations. That is all the present study claims to have done. The results of this study seem to show, however, that the logical distinctions do have a definite psychological significance.

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RELATION OF SIZE OF PUPIL TO INTENSITY OF LIGHT AND SPEED OF VISION, AND OTHER STUDIES

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In two preceding studies [1] we have shown the effect of changes of intensity of light on speed of vision under various practical conditions pertaining to the use of light. In this paper these studies are continued and the relation of size of pupil to intensity of light and speed of vision is shown.

Relation of Size of Pupil to Intensity of Light and Speed of Vision

Very little is known definitely of the effect of change of intensity of illumination on the size of the pupil over wide ranges of the intensity scale. In order to make a study of this effect and to be able to specify size of pupil under any condition of work, we have devised and constructed a pupillometer.

The features of this instrument may be roughly summarized as follows: It provides for the measurement of the breadth of the pupil to fractions of a mm within a small percentage of error; the method of making the measurement does not reduce the amount of light entering the eye or in any other way disturb the reaction to the condition being studied; the measurement may be continued without interruption through a considerable period of time; measurement is possible over a wide range of intensities; the instrument is easily and readily adaptable to a wide range of conditions of use.

[1] C. E. Ferree and G. Rand. Intensity of light and speed of vision. I. Effect of size of object and difference of coefficient of reflection as between object and background, *Jour. Exper. Psych.*, 1929, **12**, 363–391; II. Comparative effects for dark objects on light backgrounds and light objects on dark backgrounds, *ibid.*, 1930, **13**, 388–422.

The instrument is shown in Fig. 1. It consists of a telescope provided with a measuring scale extending diametrically across the field, and the auxiliary devices for adjustment needed for its precision and convenience of use. The telescope is furnished with a 12.5 cm achromatic objective, 3.2 cm in diameter, and a Ramsden eye-piece. The measuring scale is

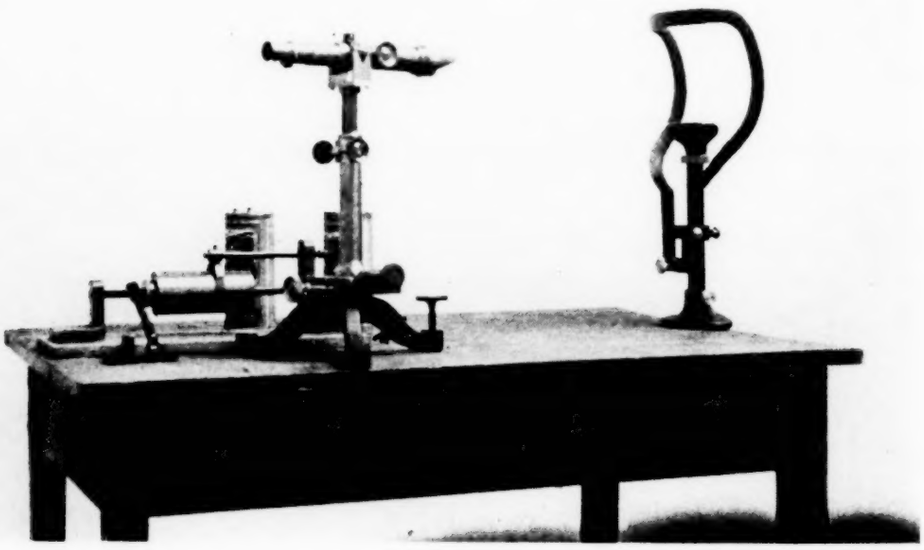

FIG. 1.

ruled on a disc of thin glass, 70 divisions to the centimeter. This scale is located in the image plane of the objective lens, and is therefore in the same plane as the image of the pupil to be measured. Image and scale are thus magnified the same amount by the eye-piece and the breadth of the pupil can be read directly in terms of scale divisions. The telescope is provided with a range of focus which permits of its use at distances ranging from 25 to 200 cm. The scale must, of course, be calibrated for the distance at which the instrument is used. This can be quickly and easily done by viewing a millimeter scale at the distance chosen and determining the relation between the two scales. In order to give a high visibility to the scale divisions as seen against the dark pupil as back-ground, an independent source of illumination is needed for the scale. The illumination of the scale is provided for as follows: A straight edge is ground on the disc

at one end of the scale. This edge is illuminated by a miniature lamp inserted in the tube shown in Fig. 1. The light passing through the glass between its two surfaces and specularly reflected from the scale divisions renders these divisions luminous and plainly visible without impairing the distinctness of the image of the iris and pupil. In order that the illumination provided for the scale may not be too high when the pupil is viewed under a low light, and conversely, this lamp is connected in circuit with a rheostat, the coil of which rotates under the contact to give small changes of resistance. The mount containing the scale is also made to rotate. This provides for the measurement of the pupil along any diameter. If viewed from a position slightly to either side of the line of sight, the vertical diameter of the pupil should be measured; if viewed from a position above or below the line of sight, the horizontal diameter is measured.

Often in the use of a telescope of this type the visibility of the object viewed can be increased considerably by shielding the objective lens from extraneous light, particularly when there is a strong component of illumination in any direction, as occurs, for example, in overhead lighting. A shield for this purpose, shaped from a section of tubing and blacked on the inside, is shown in the figure. It is held in position by a ring at one end, which slips over the end of the tube of the telescope. This shield can be rotated to cut off the light from any direction, and can be attached and removed at will.

For the convenience of use of the instrument the following adjustments are provided. The stem supporting the telescope is screwed to a plate, which can be moved to right or left in a grooved housing by a triple-pitch screw, shown in Fig. 1. This housing is in turn fastened to a plate, which can be moved forward or backward in a similar housing by a second screw. The first of these adjustments provides for the placement of the scale on the image of the pupil at divisions convenient for reading, and for following slight movements of the eye to right or left; the second, for the precise regulation of the distance of the telescope, set for a fixed focus, from the eye. The telescope itself is mounted in a collar provided with two

short studs or bosses extending out from either side. These bosses rest in adjustable friction bearings in the U-shaped housing shown in Fig. 1. This type of mounting permits of tilting the telescope up or down, as may be desired, in viewing the pupil from below or above. The telescope can be raised or lowered in the usual way by means of a rack and pinion. Finer movements are provided for by a levelling screw as shown in the figure. By means of these adjustments the instrument can be used in a variety of positions, without interfering with the use of the eye or with the reactions of the pupil to the conditions under which the eye is being used.

The effect of increase of intensity of light on size of pupil has been measured for intensities of illumination ranging from 1.25 to 100 ft. c. These determinations were made for the five backgrounds used in the experiments described in the two preceding papers (coefficients of reflection 78, 29, 21, 16, and 4 percent) and under the same conditions of size, distance from the eye, etc. for which they were employed in those experiments. In those experiments it will be remembered the test object was a broken circle mounted at the center of a dial 15 cm in diameter. The exposures of the test object were made by means of a rotary tachistoscope, devised especially for the purpose. The disc of this tachistoscope was 1 meter in diameter. The dial and disc of the tachistoscope were in the various experiments covered with pigment paper of the coefficients of reflection stated above. The remainder of the field comprised the white walls of our optics room (coefficient of reflection about 75 percent) illuminated by daylight from a skylight above provided with diffusing sashes of ground glass and by windows behind the observer. Both skylight and windows were equipped with translucent and opaque curtains to provide the small changes required to maintain a constant intensity of illumination. The distance of the test object was 2.5 meters.

The results are given in the charts shown in Fig. 2. In these charts breadth of pupil in mm is plotted on the vertical and ft. c. on the horizontal coordinate. The curves given in Chart 1 show the results for two observers for the white back-

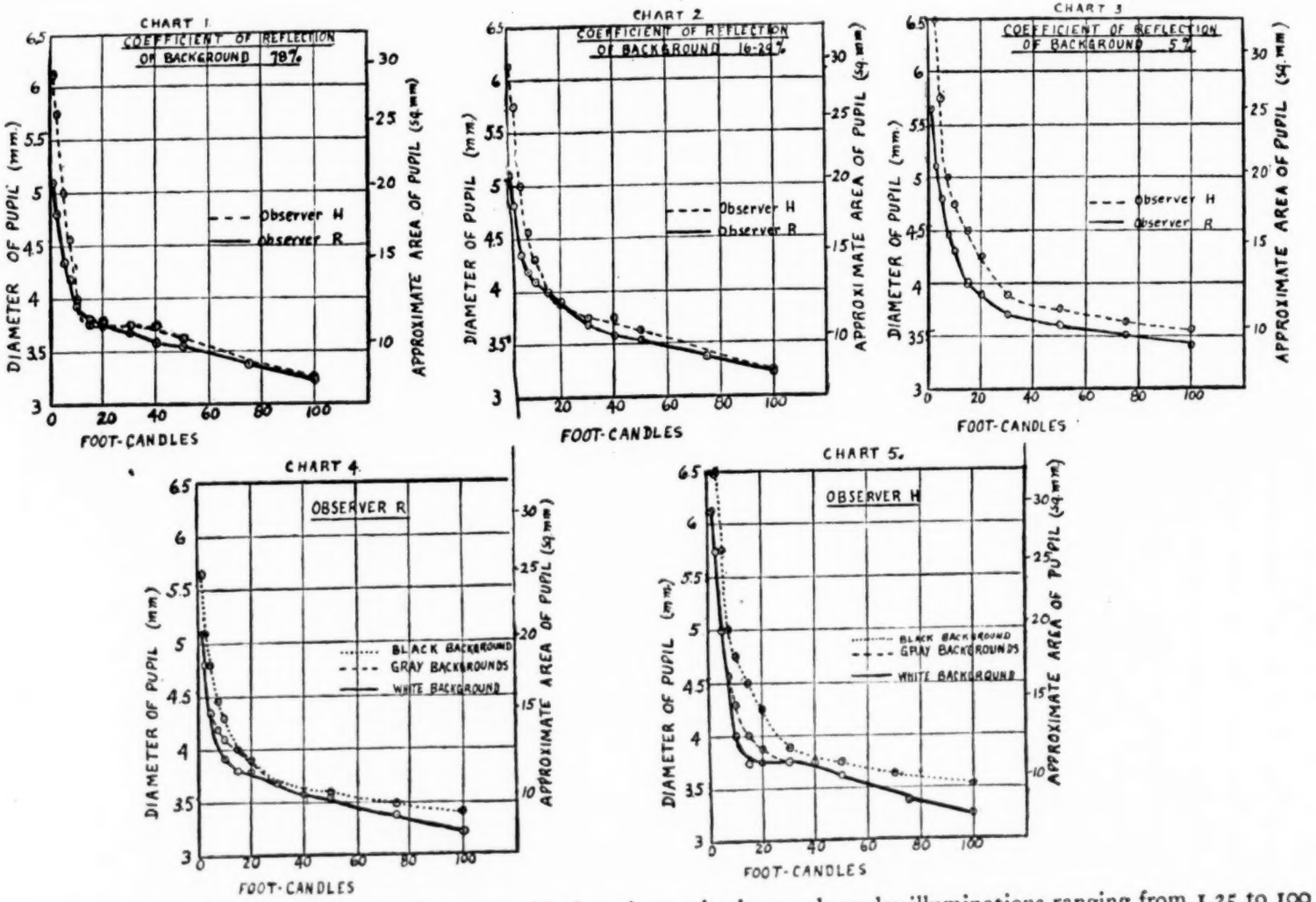

FIG. 2. Breadth of pupil in mm for white, black and gray backgrounds under illuminations ranging from 1.25 to 100 ft.c. Charts 1, 2 and 3 show the results for two observers for each background; charts 4 and 5 for the three backgrounds for each observer.

ground (78 percent coefficient of reflection); the curves in Chart 2, the results for the gray backgrounds (29, 21 and 16 percents coefficient of reflection); the curves in Chart 3, the results for the black background (4 percent coefficient of reflection); and the curves in Charts 4 and 5, the results for each of the two observers separately for the three sets of background. For the white background it will be noted that the pupil contracts rapidly from 1.25 to 10–15 ft. c. and from there very slowly to 100 ft. c. For the gray backgrounds it will be noted that the inflection of the curves is not so sharp; *i.e.*, as compared with the white background, the drop is the same from 1.25 to 7.5 ft. c., less from 7.5 to 15, greater from 15 to 40, and again the same from 40 to 100 ft. c. For the black background also the contraction is less rapid and continues to approximately 30 ft. c. The pupil is seen to be larger throughout for the dark than for the light backgrounds.

These differences in size of pupil for such slight changes in the local conditions are somewhat surprising. The types of change found are, it will be noted, the same for both observers.

Individual Differences in the Effect of Intensity of Light on the Size of the Pupil

In extending the study to include measurements of the effect of increase of intensity on size of pupil, taken for a larger number of observers, the particular interest was to compare for the different observers the range of illumination above which an increase of intensity produced little further contraction of pupil. It was suggested by Professor Dugald C. Jackson of the Massachusetts Institute of Technology that this range might be taken to represent a natural working intensity for the eye.

The conditions of work were the same as in one of the series of experiments in the preceding section, namely the series in which the white background was used. That is, the field of view comprised the dial of the test surface, the disc of the rotary tachistoscope (both covered with white paper, coefficient of reflection 78 percent), and the white walls of our optics room, coefficient of reflection about 75 percent, all diffusely illu-

minated from a skylight above and windows behind the observer. There were thus no extremes of brilliancy and the entire field was fairly uniform in brightness. The distance of the test object was 2.5 meters. The measurements of the pupil were made with the pupillometer described in the preceding section.

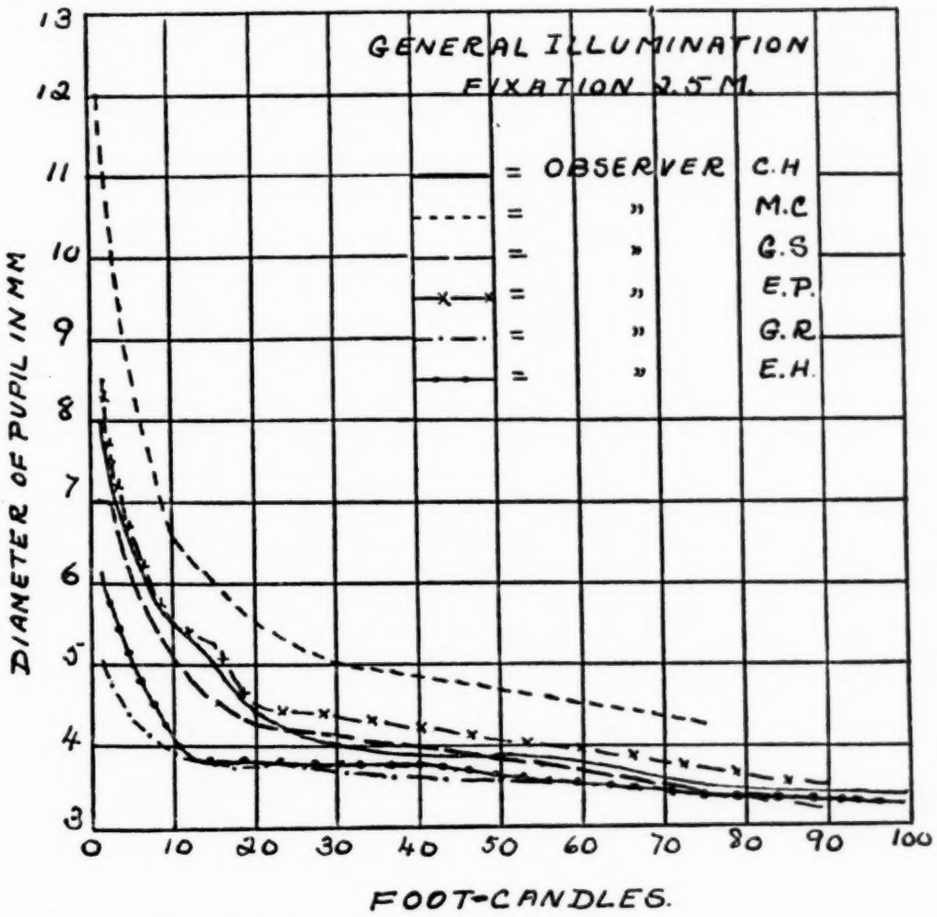

FIG. 3. Effect of increase of intensity of illumination on the breadth of the pupil in mm (6 observers).

Results are given for 6 observers in Fig. 3. While there is a wide range of variation of diameter of pupil for the various observers at any one illumination, particularly for the low intensities, the curves show a decided similarity in shape and in the location of the knee. For all observers this occurs between 10 and 20 ft. c., showing that under the conditions of work used, the pupil contracts but little for increase of intensity above this range. The work done with two observers in the preceding section showed, it will be remembered, that the introduction of a surface of lower coefficient of reflec-

tion into the center of the field of view shifted the knee of the curve from 10 to 30 ft. c.

The possibilities of effect of contraction of the pupil on speed of vision may be summarized as follows. (1) It excludes the aberration effects and other irregularities of focussing resulting from the use of the periphery of the lens. (2) By narrowing the cone of light which comes from each point in the object and which must be brought back to a point in forming the image, it reduces the size of the diffusion circles produced by faulty focussing. A rough demonstration of the importance of these types of effect was made as follows. A projection apparatus was constructed and a broken circle imaged on a screen. When the apparatus was correctly focussed, the effect on the clearness of the image formed, produced by contracting the pupillary aperture, while noticeable, was not great. When poorly focussed, however, the effect was very striking,—a fair degree of clearness being obtained with a small aperture from an image which had been so badly blurred as to be scarcely distinguishable when a large aperture was used. As bearing on the results of the experiments on speed of vision, contraction of the pupil could thus be conceived as acting in two ways: (*a*) with a given precision of adjustment of the lens, a clearer image would be formed; and (*b*) less precision of adjustment of the lens would be required to produce a given clearness of image. Either or both of these results would tend to reduce the time required for the discrimination of the object. (3) It increases the effect of the diffraction patterns formed about each point in the image. This action which tends to blur the image becomes significant probably only with very small sizes of pupil. And (4) it decreases the amount of light entering the eye.

In order to obtain a more definite idea of the effect of changes in the size of the pupil on speed of vision, it was decided to make the determinations of speed with an artificial pupil for comparison with determinations made with the natural pupil under the same conditions with regard to size of object, background, and intensity of illumination. The determinations have thus far been completed only for the 3 and

5.2 min. sizes of visual angle and the 78 percent coefficient of reflection of background. The range of illumination was 1.25 to 100 ft. c.; coefficient of reflection of the test-object 3 percent. The breadth of artificial pupil employed was 2.8 mm. This was slightly smaller than the natural pupil at the highest illumination used, 100 ft. c. The artificial pupil was placed 1 cm in front of the cornea of the eye. The results for the determinations with the natural and the artificial pupil are shown for comparison in Fig. 4.

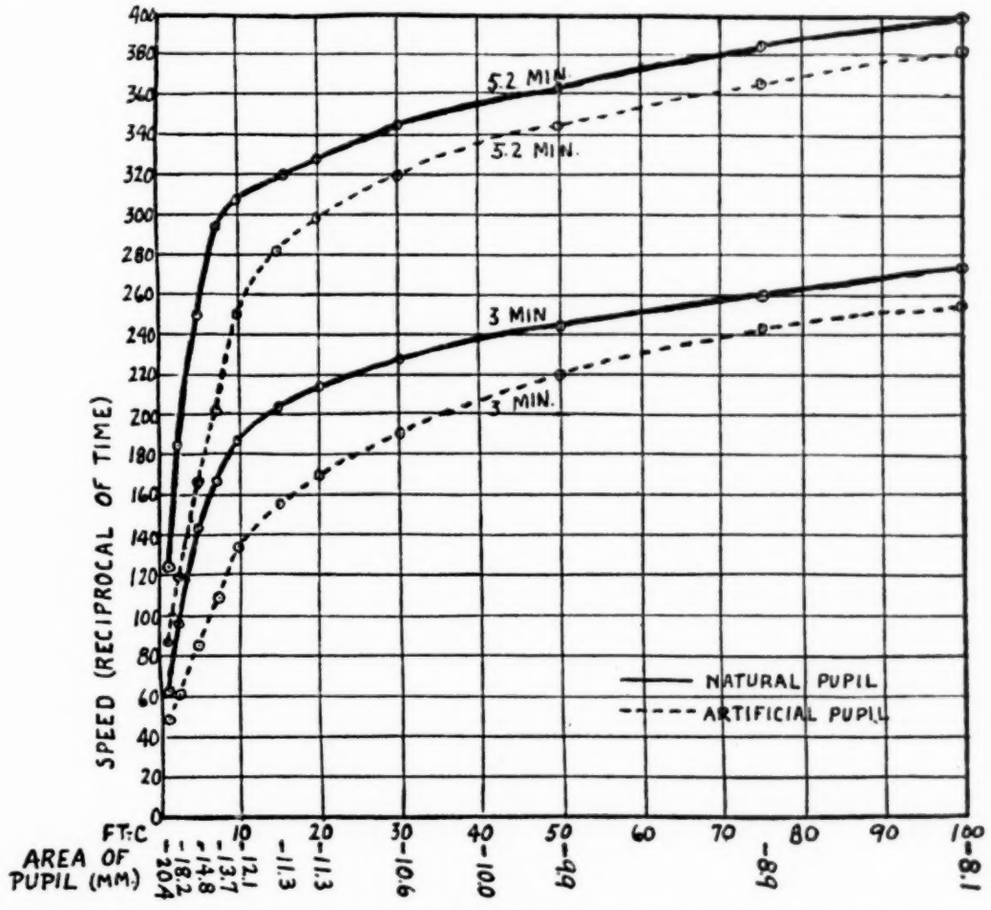

FIG. 4. Curves showing a comparison of the results for the natural and an artificial pupil. The breadth of the artificial pupil employed was 2.8 mm. The breadth of the natural pupil ranged from 3.21–5.1 mm. The artificial pupil was placed at a distance of 1 cm in front of the cornea of the observer's eye.

It is seen in this chart that the reduction of speed by the use of the artificial pupil is slight at the very high illuminations. It gradually increases through the medium illuminations, and becomes marked in the region from 5 to 10 ft. c. For the very lowest illuminations (2.5 and 1.25 ft. c.) the re-

duction of speed was again less in spite of the great reduction in the amount of light entering the eye. In these cases there is apparently a gain in focussing action by the use of the artificial pupil which partially compensates for the loss of light.

One of the reasons for making the determinations with an artificial pupil was to ascertain whether the speed of the eye's reaction would more closely approximate a logarithmic function of intensity if variations in the size of pupil were eliminated. In order to make the comparison needed to give this information, the results with both the natural and the artificial pupils were plotted against log. intensity in ft. c. These plots are shown in Fig. 5. An inspection of the curves given

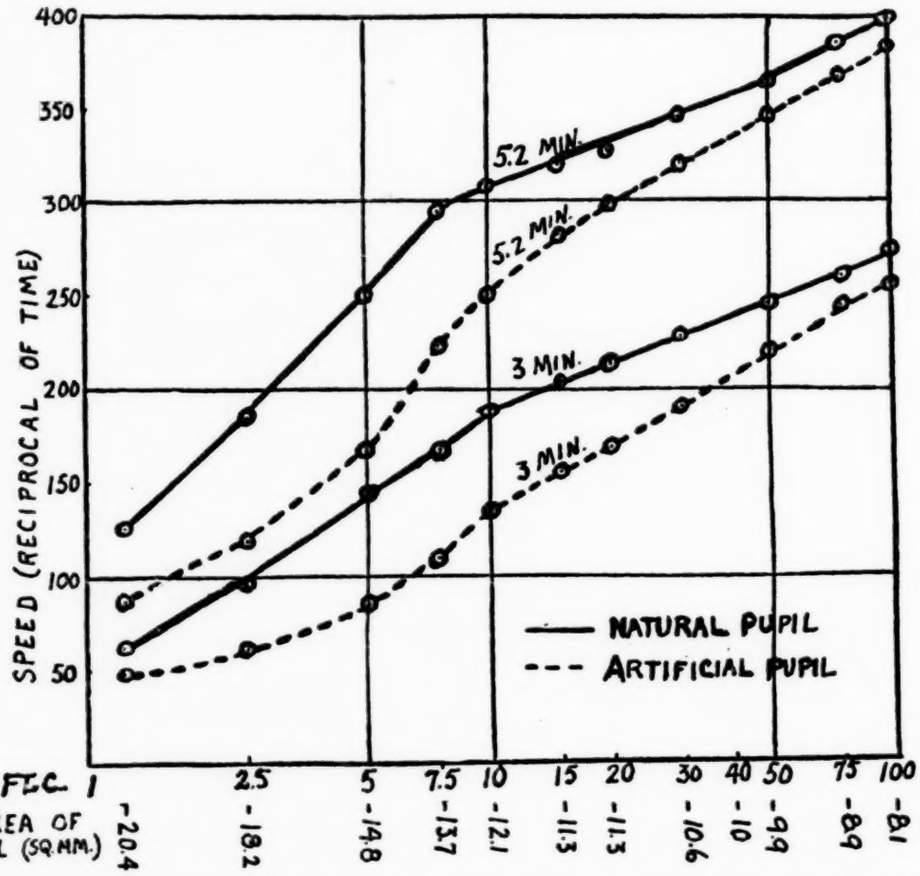

FIG. 5. Curves showing the results for the natural and the artificial pupil in which speed is plotted against log. illumination in ft.c.

in Figs. 4 and 5, shows (1) that speed is not a simple logarithmic function of intensity over the entire range of intensities investigated for either the variable or the constant size of pupil. (2) For the natural pupil the curve is made up of two approx-

imately straight arms of different slope, the point of junction being for each size of object at or near 10 ft. c. And (3) the curves for the artificial pupil show an approximately logarithmic relationship from 10 to 100 ft. c.; below 10 ft. c. the tendency seems to be towards direct proportionality. For both sets of curves 10 ft. c. is apparently a significant point in the intensity scale. For the background used in this determination, the knee of the curve for size of pupil came also, it will be remembered, at or near 10 ft. c.[2]

In later studies this attempt at analysis and evaluation of factors entering into the relation between speed of vision and intensity of illumination will be continued. One of these studies will comprise, for example, the determination of speed for a constant size of pupil in which the amount of light entering the eye will be made the same for the artificial pupil as for the natural pupil at each intensity of illumination. The difference in effect then between the results for the natural and the artificial pupils should represent the effect of changing size of pupil on the clearness of the image formed.

[2] Space has not been taken here to give all the curves plotted against log. ft.c. When plotted on this scale a distinct tendency towards two slopes is shown in all cases for the range of illuminations employed (1.25 to 100 ft.c.). For the background having a coefficient of reflection of 78 percent the point of junction between the slopes occurs at 10 ft.c. for all five sizes of object. For the 2, 3, 4.2 and 5.2 min. visual angles the slope is steeper below 10 ft.c. and more gradual from 10 to 100 ft.c. For the 1 min. visual angle it is more gradual below 10 ft.c. and steeper between 10 and 100. For the three gray backgrounds with all five sizes of object the slope is with one exception (5.2 min. visual angle on the background of 29 percent coefficient of reflection) more gradual for the lower and steeper for the higher intensities. The point of junction for these backgrounds, however, is not always at 10 ft.c. For example, for the two darkest backgrounds, coefficient of reflection 21 and 16 percent, it comes at 2.5 ft.c. for the 4.2 and 5.2 min. visual angles, and at 5 ft.c. for the 3 min. visual angle. The curve which shows most nearly a simple logarithmic relation is the one for the 3 min. visual angle on a background of 29 percent coefficient of reflection. It would seem then that the influence of the factors which affect the relation between intensity of light and speed of discrimination at different levels of the intensity scale for different sizes of object and with different differences in coefficient of reflection between object and background, is too complex to permit of any simple formulation that would be valid for all conditions.

The Effect of Intensity of Light on Speed of Vision for a Brass Test-object on a Steel and a Steel Test-object on a Brass Background

This test was made at the suggestion of Professor Dugald C. Jackson of the Massachusetts Institute of Technology, who proposed that the effect of intensity of light on speed of vision be determined for a color difference between object and background typical of differences frequently found in industrial situations. The test-objects used were prepared under the direction of Professor J. W. Barker of the same institution. Broken circles were cut from brass and steel of such a size that the openings would subtend a visual angle of 3 min. with the eye placed at a distance of 2.5 meters. These test-objects were sunk in steel and brass discs respectively, 13 cm diameter and 1 cm thick. The broken circle in each case was flush with the surface of the disc. The steel reflected 21 percent of the incident light when viewed at an angle which gave no specular reflection; the brass, 26 percent. The steel letter was thus viewed on a slightly lighter yellowish background and the brass letter, on a slightly darker gray background. The preëxposure was in both cases to a gray of the brightness of the background. Care was taken at all intensities to view the test-objects and their backgrounds at an angle that gave no specular reflection.

The results for these two conditions are given in Fig. 6. It will be seen from the curves that the speeds of discrimination of these 3-min. test-objects which have only a color and slight brightness difference from their backgrounds (coefficients of reflection 21 and 26 percent) are of the same order of magnitude as the speeds for a 1-min. black test-object on a white background (coefficients of reflection 4 and 78 percent). The speed curve for this test letter is reproduced in Fig. 6 for comparison.

In these curves the following points may be noted: the rapid initial rise which is characteristic of the curves for the larger visual angles; the higher speeds and greater steepness of the curve for brass on steel as compared with that for steel on brass, which is characteristic of the curve for a light object

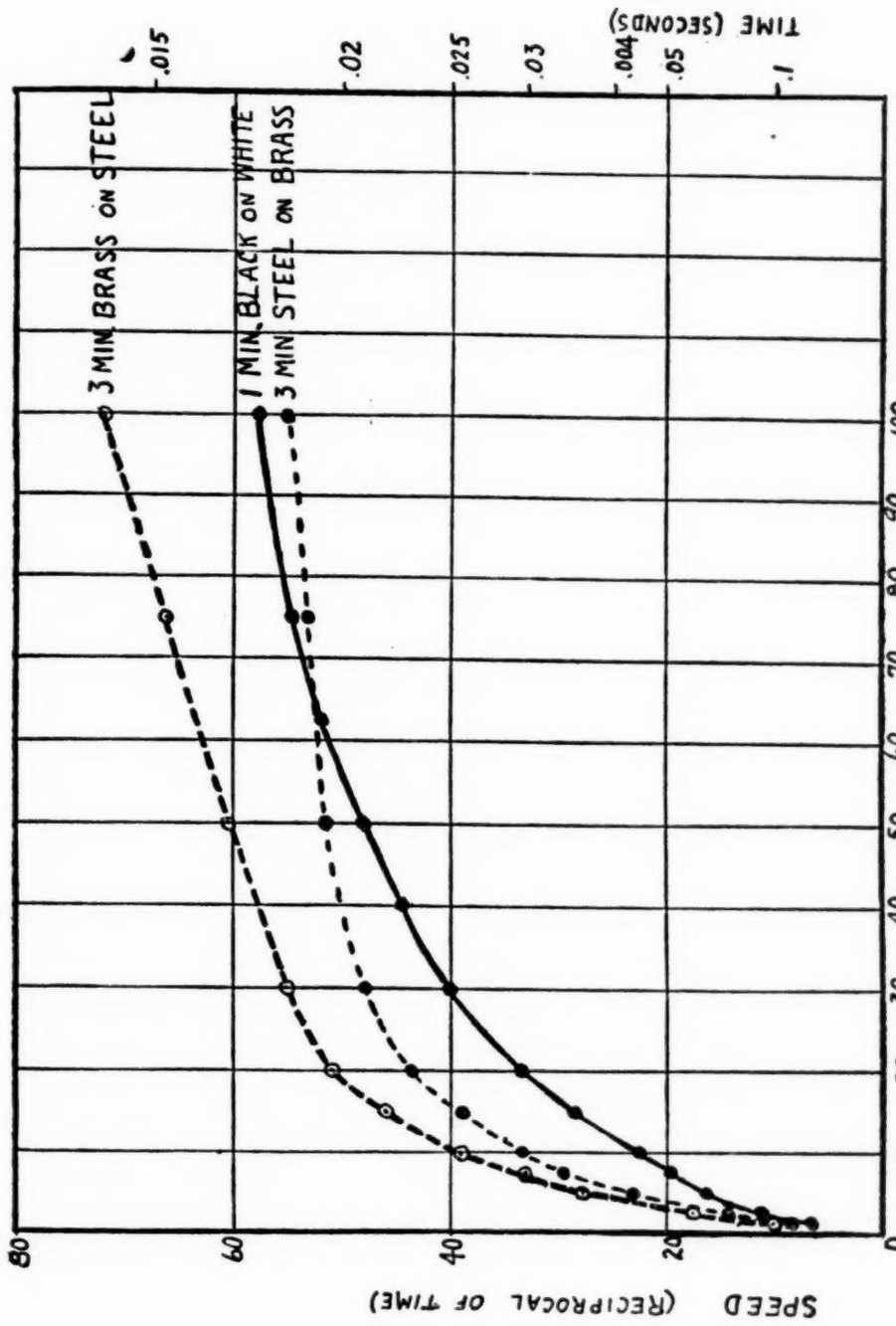

FIG. 6. Effect of increase of intensity of illumination on speed of discriminating a brass test-object on a steel background and a steel test-object on a brass background. (Visual angle 3 min. Coefficient of reflection of the brass 26 percent; of the steel 21 percent.)

of this size on a dark background; and the flattening of the curve for steel on brass at the higher intensities, as compared with that for brass on steel, which is characteristic of the curve for a dark object on a light ground.

The Effect of Intensity of Illumination on the Speed of Reading a Steel Vernier Rule to 1/1000 inch

This test also was made at the suggestion of Professor Jackson, who proposed that the effect of increase of intensity of light on the speed of performing some typical industrial task which involved several eye movements be determined. In conducting the test special care was taken to make the test conditions conform as closely as was feasible to working conditions.

The test-object was a steel rule with a vernier reading to 1/1000 inch. The rule used had been in service for some years, but still retained considerable polish. It was mounted normal to the observer's eye at a convenient working distance, 10 in. At this distance the visual angle subtended by 1/1000 inch is 21 sec. of arc.[3] Early in the test it was found that the highest

[3] It may seem somewhat surprising that such a small detail could be read. It must be remembered, however, that the test-detail, namely, the just noticeable separation of two vertical lines, presented the simplest possible task for discrimination; that maximum advantage was taken of specular reflection; and that the discrimination was made under conditions of near seeing,—in which case powers of discrimination are known to be more acute than for far seeing, the condition under which acuity is usually rated. In this connection it will be remembered that it was our purpose to plan an experiment which would involve several searching movements of the eye guided by the discrimination of coarse detail and would end with the discrimination of a definite small or fine detail subtending somewhere near the threshold or limiting acuity angle. In order to secure the discrimination of a detail the size of which could be definitely specified as the final event in the ocular series, an assistant in advance of the experiment set the vernier under high magnification so that some line of the one scale coincided exactly with a line of the other scale. The scale divisions on either side then deviated from coincidence by 1/1000 inch. In reading the rule the method followed was first the reading of the coarser details (the tenth-inch numbers and the quarter divisions within the tenth) and then the determination of the point of exact coincidence of a line of one scale with that of a line of the other. Since the observer knew in advance that the scales were set to exact coincidence at some point, this latter determination resolved into the location of the points of least separation between the lines of the two scales. The location of these points, one lying on either side of the point of coincidence, required the discrimination of a detail of 1/1000 inch. The final task set for the eye was thus the discrimination of a detail of 1/1000 inch.

visibility was given to the graduations when the surface of the rule was viewed by specular reflection. A correct reading of the scale required, however, that the rule be held normal to the line of sight. In conducting the test, therefore, the rule was mounted normal to the line of sight and in such relation to the incident light as to give the greatest amount of specular reflection that could be obtained with the eye in the correct reading position. This, it is assumed, would be the position in which it would be held in actual work. The source of illumination used for the lower intensities was a Macbeth daylight unit of the type designed for use in studios. For the higher and medium intensities it was supplemented by window-light and skylight. These sources, particularly the white lining of the reflector of the daylight unit, were mirrored quite strongly on the polished surface of the rule but not on the graduations which had become blackened from grease and dirt during use.

It was of course impossible to vary the illumination of the room and the brightness of the surface of the rule in any fixed relationship over the entire scale of intensities used. That is, the brightness was disproportionately high at the lower range of intensities because a high component of specular reflection could be obtained with the Macbeth daylight unit and the window-light as sources; and disproportionately low at the upper range of intensities because only a small component of specular reflection was added by the skylight as source. Both brightness and illumination measurements were made, but since it was obvious that the speed of reading the rule varied with the brightness of its surface and not with the illumination of the room, only the former readings are given in the chart of results.

Only one eye was used in making the determinations. Two reasons may be assigned for this. (*a*) Because of the difference in the angle of view, the apparent brightness of the surface of the rule was different for the two eyes. And (*b*) because of the resultant parallax, the reading of the vernier differed for the two eyes by at least 1/1000 of an inch.

The tachistoscope was geared to give very long exposures. The preëxposure was to a gray selected to match the surface of the rule as closely as possible in brightness. In the long

exposure-times needed to read the rule, however,—of the order of seconds rather than thousandths of a second as in former tests,—the factor of preëxposure was probably negligible.

The task set to the observer consisted in reading the tenth-inch numbers, the quarter divisions within the tenth, and the exact position of the vernier divided into twenty-fifths. This last reading which necessitated searching movements of the eye, constituted the chief difficulty of the task. An accuracy of 75 percent (six correct judgments out of eight) with no error greater than 1/1000 inch was required of the observer in the determination of the speed with which the task could be performed.

A long period of training was necessary to bring the observer to the limit of practice. The training consisted primarily in learning to gauge the approximate vernier reading from the position of the indicator within the quarter division, thereby eliminating unnecessary searching movements. The task was relatively easy at the high intensities. At the low intensities, however, it was very difficult to decide quickly which of two or three readings was the correct one. The test demonstrated very strikingly to the observer the advantage of utilizing specular reflection in those cases in which an object giving little or no reflection is viewed against a polished background. The case in question was an ideal example of this relation. By the proper adjustment of the illumination, the tarnished and dirt-filled scratches reflecting little or no light could be made to stand out in strong contrast to the high brilliancy of the polished background. When both object and background are polished, however, as was the case for the brass and steel combinations described in the preceding section, specular reflection is a disadvantage, tending to obscure rather than to differentiate the details to be discriminated.

The results are given in Fig. 7. The range of illumination covered was from 7.5 to 181 ft. c., giving brightnesses on the surface of the rule ranging from 19.4–191.5 ml.[4] The time of

[4] The above values may be reduced to apparent foot-candles and foot-lamberts by multiplying by 0.929. The specification in terms of these units might perhaps seem more obviously comparable with the specification in ft.c. used in other portions of the paper.

exposure at the lowest brightness was 3.9 sec. As this was the longest exposure that could be obtained with our tachistoscope, we were unable to make determinations for lower intensities. The time of exposure at the highest brightness was 1.23 sec., a gain in speed of 217 percent as the result of increas-

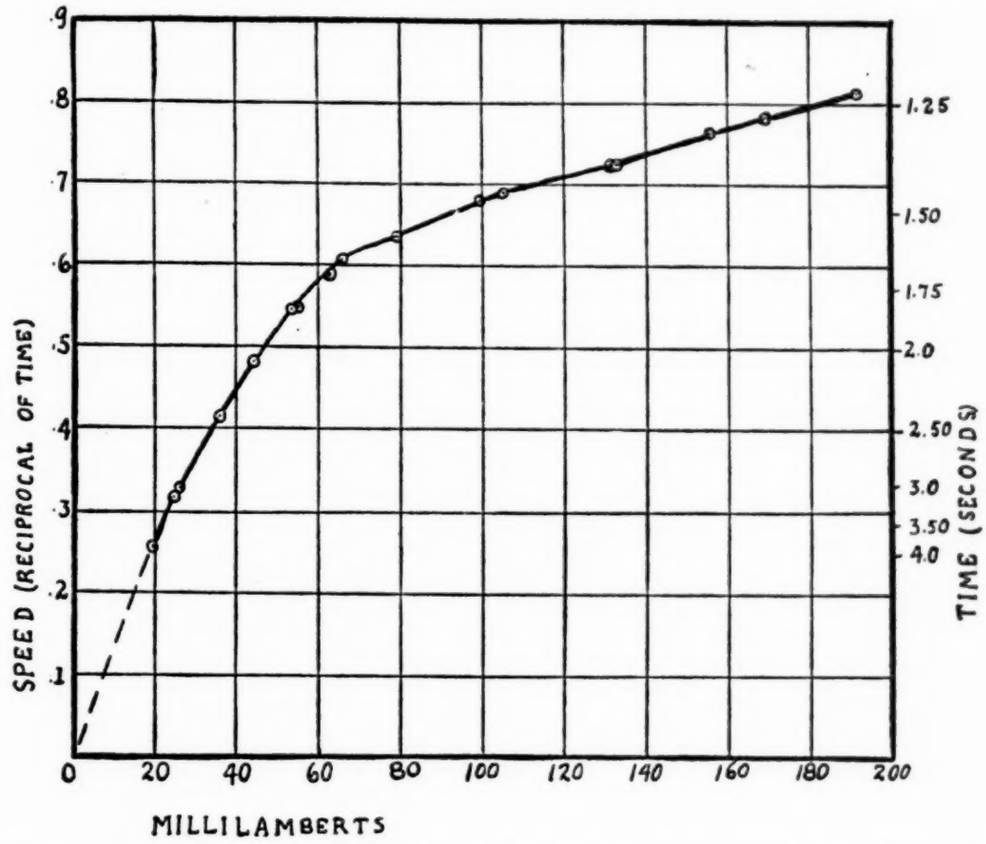

FIG. 7. Effect of increase of intensity of illumination on the speed of reading a steel vernier rule to 1/1000 of an inch. (Visual angle 21 sec.)

ing the intensity of illumination. The knee of the curve occurs at approximately 66 ml. The results show that the typical shape of intensity-speed curve for a dark object on a lighter background is given, although in this case as compared with previous experiments, several eye-movements were involved in the task, the exposure-time was much longer, the detail to be discriminated much smaller, and the range of intensity of illumination used much higher. This experiment serves to indicate to what extent speed of work of a factory type, involving an important use of the eyes, may be increased by increasing the intensity of light when the work is done under controlled conditions.

Conclusions

(1) Speed of discrimination and its rate of change with increase of intensity of light are affected by changes in the size of the pupil, as is shown by experiments with a variable and a constant size of pupil. For the range of illuminations used and the conditions tested, speed of discrimination is not a simple logarithmic function of intensity with either the natural or an artificial pupil.

(2) When a white background was used (coefficient of reflection 78 percent) the pupil contracted rapidly for changes of intensity ranging from 1.25 to 10–15 ft. c.; for intensities higher than this the rate of change was very slow. For the gray backgrounds (coefficients of reflection 16, 21 and 29 percent) the rate of contraction was in comparison not quite so rapid under 15 ft. c.; a little more rapid from 15 to 40 ft. c.; and approximately the same from 40–100 ft. c. From this it will be seen that contraction of pupil is not an important factor in the comparatively slow rate of change of speed of discrimination which takes place with increase of intensity at the higher illuminations. The explanation is to be found primarily perhaps in the effect of change of intensity at the higher illuminations on the retinal functions:—persistence of vision, rate of rise of sensation, differential sensitivity, adaptation, etc.

(3) The size of the pupil is affected by other components of illumination besides the one coming from the object viewed. It is also affected by the size as well as the brightness of the illuminated area.

(4) Curves representing the effect of increase of intensity of light on the size of the pupil for six observers have a sharp inflection located between 10 and 20 ft. c. That is, for this group of observers increase of intensity beyond this range has very little effect on the size of the pupil for the conditions tested. It has been suggested that this range of intensities might represent a natural working intensity for the eye. It seems obvious at least that so far as the contribution of the pupil is concerned, the maximum efficiency of the eye can not be obtained below this level of intensity, for with an expanded

pupil the maximum clearness of image can not be given by the refracting system of the eye.

(5) The curves representing the effect of increase of intensity of light on the speed of discriminating a 3-min. brass test-object on a steel background and a 3-min. steel test-object on a brass background, have approximately the same height as for a 1-min. black test-object on a white background. The curve for brass on steel is higher, steeper and less flattened at the high intensities than that for steel on brass. These results are in general in agreement with those obtained for light objects on dark backgrounds as compared with dark on light.

(6) The curve representing the effect of increase of intensity of light on the speed of reading a steel vernier rule to 1/1000 inch is similar in shape to those previously obtained for speed of discriminating black objects on gray backgrounds. The knee of the curve occurs around 66 ml or 60 apparent ft. c. The speed at the highest brightness used is more than three times that at the lowest. This task, which involves several eye-movements during the exposure, is more complicated and more typical of the ordinary use of the eyes than that set in previous experiments. It is interesting to note, therefore, that the same type of curve is obtained as in previous experiments, although the detail to be discriminated was much smaller, the range of intensities used much higher, and the exposure-times necessary for discrimination much longer. Moreover, the experiment shows to what extent speed of work of a factory type, involving an important use of the eyes, may be increased by increasing the intensity of light when the work is done under controlled conditions.

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AN EXPERIMENTAL STUDY OF REFLEX AND VOLUNTARY EYELID RESPONSES

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The Problem

The purpose of the present study was to determine the differential reaction time of the reflex and voluntary eyelid responses as dependent upon the interval between the various stimuli. The following aspects of the main problem were also considered: (1) the relation between electrically stimulated and mechanically stimulated reflexes, and (2) the effect of the refractory phase phenomenon (as the term is used in physiology and neurology) on the reaction time of the reflex and the voluntary eyelid responses. This last point is perhaps the most important phase of this study and at the same time presents the greatest difficulty of determination.

We are indebted to the physiologists for the discovery of the refractory phase phenomenon and for most of the known facts about its operation. This phenomenon was first found in the heart muscle by Kronecker and Stirling (1874). Marey (1876) demonstrated the same phenomenon and gave it its present name. He showed that the heart has a period of inexcitability during which it will not respond to stimuli and this period occurs during the systole. Romanes (1877) demonstrated the same phenomenon in the Medusa. The discovery of a similar phase in the central nervous system was made by Broca and Richet (1897). The phenomenon of refractory phase was found in a variety of neuro-muscular systems by Verworm (1913); in the nerve by Gotch and Burch (1899), and by Lucus (1917). Zwaademaker and Lans (1899) showed the existence of a refractory phase in the eye-

[1] This study was carried out in the Jesup Psychological Laboratory under the direction and supervision of Dr. Joseph Peterson to whom the writer gratefully acknowledges valuable assistance.

lid reflex. A similar phase was shown to exist in the knee-jerk by Dodge (1910 and 1927), and also in the eyelid reflex (1913 and 1927); and in the start reflex of the guinea-pig it was found by Dodge and Louttit (1926) and also by Cohen (1929).

Telford (1929) in a study of "The Refractory Phase in Voluntary and Associative Responses" drew the following conclusions from his results: "Voluntary responses, judgments and simple associative responses do produce effects in the organism which serve as a barrier against immediate repetition." "The subsequent recovery and return to approximate normality, as it manifests itself in the way here investigated, is comparable to that found in isolated tissues and reflexes." The implication here, presumably, is that the voluntary and associative responses follow the characteristic refractory phase curve of the nerve or muscle preparation though not in the same absolute time periods (Lucus, 1909).

The complete period of recovery has generally been divided into three distinct periods. There is first an 'absolute refractory period,' during which the tissue is inexcitable. Then follows the 'relative refractory period' during which the excitability returns gradually to normality. This period of impaired excitability is followed by one in which the irritability is greater than normal. This has been called the 'supernormal phase.' Then comes the return to normal (Adrian and Lucus, 1912; Lucus and Adrian, 1917). It should be borne in mind, however, that the above characteristics of the recovery period are based on results obtained on elementary tissues, with time intervals between stimuli of .01, .02, and .03 sec. The fundamental problem then is the extent to which we are justified in assuming that voluntary responses are determined in the same manner.

The particular attack on the present problem, in part, grew out of the work of Telford on voluntary and associative responses. It was an *a priori* assumption on the writer's part that an intensive study of the reflex and voluntary eyelid responses would yield valuable data on the problem of individual differences as well as on the nature of the reacting mech-

anism in general. In dealing with an organism which presents such a vast complexity of neural organization as does that of the human being, we are seriously handicapped in the formulation of general laws of behavior by two kinds of variability. In the first place no two persons react in exactly the same way to identical stimuli, and in the second place the same individual does not always react similarly to the same stimulus (Dodge, 1927). The advancement of psychology as a science will depend upon the recognition of these fundamental characteristics of human behavior and upon our efforts to understand better these phenomena.

No systematic investigation has been reported on the effect of the length of the interval between stimuli on the reaction time of the reflex or voluntary eyelid responses, longer than .5 sec. (Dodge, 1913 and 1927). The scope of the present study was, therefore, limited to an investigation of the effect of this temporal factor on the reaction time of the reflex and voluntary eyelid responses.

Apparatus

In an experiment of this kind it is necessary to have some accurate mechanical means of giving the stimulus at the desired intervals and also of recording the instant of response. The photographic technique of studying eye movements, while offering certain advantages of refinement, has certain practical disadvantages. The initial cost of the equipment is rather high, as is also the cost of operating when the nature of the work requires the recording of a large number of reactions. In view of these considerations it seemed worth while to devise a piece of apparatus that would be less expensive and at the same time satisfactory for most purposes. The apparatus described in this experiment grew out of a very practical need in connection with a series of researches on various phases of the eyelid response. This apparatus has been described in detail elsewhere.[2]

Closure of the lids may be caused by a very bright light entering the eyes, by the sudden approach of some foreign

[2] Allison, L. W., Apparatus for studying eyelid responses, *Amer. J. of Psychol.*, 1930, 42, 634–635.

body, by contact of a foreign body with the lashes, by irritation of the cornea or conjunctiva, and by sudden sound. Starling (1926) says: "The reflex apparently can be initiated by the stimulation of any of the branches of the ophthalmic (1st) division of the 5th (trigeminal) nerve. From the nucleus of this nerve in the pons Varolii fresh fibers take the impulses, it is believed, to the upper part of the facial nuclei of both sides (7th nerve), and from these to the orbicularis palpebrarum" (p. 411). Zwaardemaker and Lans (1899), in a study of the refractory phase of the wink reaction, used two forms of stimulation: flashes of light and puffs of air blown against the cornea. Dodge (1913), in commenting on their method of stimulation, says: "Both are normal, adequate stimuli for the protective wink. But they have the common disadvantage that the receptors are affected by the reaction as well as by the stimulus." In view of this fact Dodge recommended, and has used, a sharp noise as the stimulus for the protective wink. This noise was produced by a spring-driven snapper which struck the closed side of a sounding box, being released by electromagnetic triggers. This method would necessitate the setting of the snappers after each pair of stimuli and would not, therefore, be adaptable to the investigation of our problem. In considering the various methods of stimulating the eyelid reflex we had to be governed by the nature of our problem which necessitated the giving of a large number of stimuli in succession. It was finally decided to use electrical and mechanical stimulation for the reflexes and a telegraph sounder for the voluntary responses.

Procedure

In the first part of this study, 56 voluntary and 56 reflex responses were taken on each of ten subjects at each of the four intervals, 1/2, 1, 2, and 4 sec., making a total of 224 responses for each subject taken at the same sitting. For the voluntary responses, in this series, the telegraph sounder was placed on a table about one meter from the subject's head. This was sufficiently removed from the subject not to produce a reflex wink and at the same time close enough to be heard

distinctly. Each subject was instructed to respond by winking one time as quick as possible when the sound was heard. The electric stimulus for the reflex consisted of the current from three dry cell batteries passed through an induction coil in a fixed position. The 'indifferent' electrode consisted of a cup of salt water into which the fingers of the subject's left hand was placed. The 'active' electrode, where the effect of the current was more pronounced, consisted of a thin piece of brass 1 × 2 cm, which was placed over the infraorbital branch of the maxillary (second division of the trigeminus) as it emerges through the infraorbital foramen of the maxillary bone of the subject's face. For the reflex responses, the subject was instructed "to take a passive attitude, so far as possible, toward the stimulus and to avoid winking voluntarily on the one hand and inhibiting the wink on the other hand." The strength of the current was just sufficient to produce the reflex and the stimulus was not uncomfortable. Approximately 16 preliminary stimuli (not recorded) were given each subject to acquaint him with the nature of the stimulus. After the 'spectacles' had been properly adjusted and the strength of the current regulated, the experiment proper was begun.

In order to equate the influence of such factors as fatigue, practice, adaptation, etc. on the reflex and voluntary responses, the following order was observed: one series of voluntary responses, followed by two series of reflex; by two of voluntary; by two of reflex, and by one of voluntary. Each series here consisted of 14 responses to each of the four intervals given according to a prearranged chance order schedule. The subject was given approximately 30 sec. rest between each series.

For the purpose of making comparisons between the electrically stimulated and the mechanically stimulated reflexes, eight of the same ten subjects were taken through a second series of experiments. Only the reflex responses were considered this time, consisting of 34 reactions to each of the four intervals. These were obtained in five series, the subject resting approximately 30 sec. between each series. The mechan-

ical reflex was produced by a light tactual stimulation on the lower lid of the subject's left eye (the same eye as that to which the recording device was attached). The attachment on the Hopkins Chronoscope for giving tactual stimuli was used to produce this reflex response. The subject was seated by a table to which was fastened an adjustable head-rest. To the edge of this same table was fastened an upright rod, 24 in, to which a horizontal rod, 14 in, was fastened by means of a clamp. This gave both vertical and horizontal adjustment. The electro-magnetic tapper was attached to the horizontal rod. While the subject's head was supported in the head-rest, in a comfortable position, the tapper was adjusted to within about 3 mm of the face, and about 5 mm below the free margin of the subject's left lower eyelid. This method was found to be a very effective means of producing the reflex eye-wink. Each subject was instructed, as in the electrical set-up, 'to take as thoroughly a relaxed and passive attitude toward the situation as possible.'

All the subjects in the experiment, except No. 1 and No. 4, had had at least some experience in experimental psychology involving the use of apparatus, both as subject and as experimenter. This precaution was taken in order to insure the highest possible degree of coöperation in the carrying out of the study. The subjects used in this study (8 men and 2 women) were students in Peabody College. Seven of the ten subjects used were graduate students doing work above the master's degree. The other three subjects were seniors in college.

Results

In the planning and carrying out of this investigation every effort was made to give due consideration to the most minute details of each individual record as well as to the mean of the group in the various experiments. For that reason the results will be presented in graphic and tabular form as nearly complete as possible both for the group and for the several individuals.

Table 1 shows the results for the voluntary eyelid responses at each of the four intervals in terms of the mean,

TABLE 1

VOLUNTARY EYELID RESPONSES

Intervals Between Stimuli	½ sec.			1 sec.			2 sec.			4 sec.		
Subject	Mean*	M.V.	V.	Mean	M.V.	V.	Mean	M.V.	V.	Mean	M.V.	V.
1	293.6	56.2	.19	188.2	42.3	.22	207.2	45.3	.22	226.4	38.0	.17
2	184.7	70.3	.37	179.2	29.7	.17	182.8	26.2	.15	193.6	33.8	.18
3	187.0	61.4	.29	178.4	35.8	.20	147.0	22.5	.15	162.2	32.1	.21
4	181.4	31.3	.13	163.4	18.5	.11	153.8	20.1	.13	183.4	16.1	.08
5	414.2	51.4	.13	392.2	84.3	.22	359.8	75.3	.26	393.0	67.1	.18
6	203.8	53.6	.26	180.0	60.0	.34	181.4	34.0	.18	216.6	30.2	.14
7	173.8	38.1	.22	181.4	34.3	.19	179.6	35.3	.20	202.8	35.1	.18
8	146.4	21.7	.15	152.2	20.4	.14	152.6	19.2	.13	191.4	25.9	.14
9	186.0	31.8	.17	176.4	35.9	.21	162.4	23.3	.14	188.4	33.0	.18
10	228.2	52.3	.22	255.4	64.2	.26	236.4	53.6	.22	240.0	51.4	.22
Average of all S's...	219.9	46.8	.21	204.7	42.5	.21	196.3	35.5	.18	219.8	36.3	.17
P.E.....	12.46			11.36			8.21			9.69		

* Each of these means for the several individuals was found from 56 responses.

the mean variation, and the coefficient of variability $\left(\frac{M.V.}{M}\right)$ for each of the ten subjects separately and also for the entire group. An examination of this table will show that, in terms of the average of the ten subjects' records, the 2-sec. interval is the most favorable for quickness of response. There is practically no difference between the 1/2 and 4-sec. intervals, the reaction time being 219.9 ± 12.5 for the 1/2-sec. and 219.8 ± 9.7 for the 4-sec. interval. These results are also shown graphically in Fig. 1. This curve shows the mean reaction time for the ten subjects at each of the four intervals. From this composite curve it may be seen, as well as from Table 1, that the 1/2 and 4-sec. intervals are decidedly the most unfavorable (of those tried) to quickness of voluntary reaction time. The 2-sec. interval is the most favorable as judged by the reaction time. The difference is slightly greater between the 1 and 2-sec. intervals than between the 1/2 and 4-sec. intervals. When the average of the group is considered one would be inclined to conclude that there is some rather stable and consistent physiological factor operating in such a way

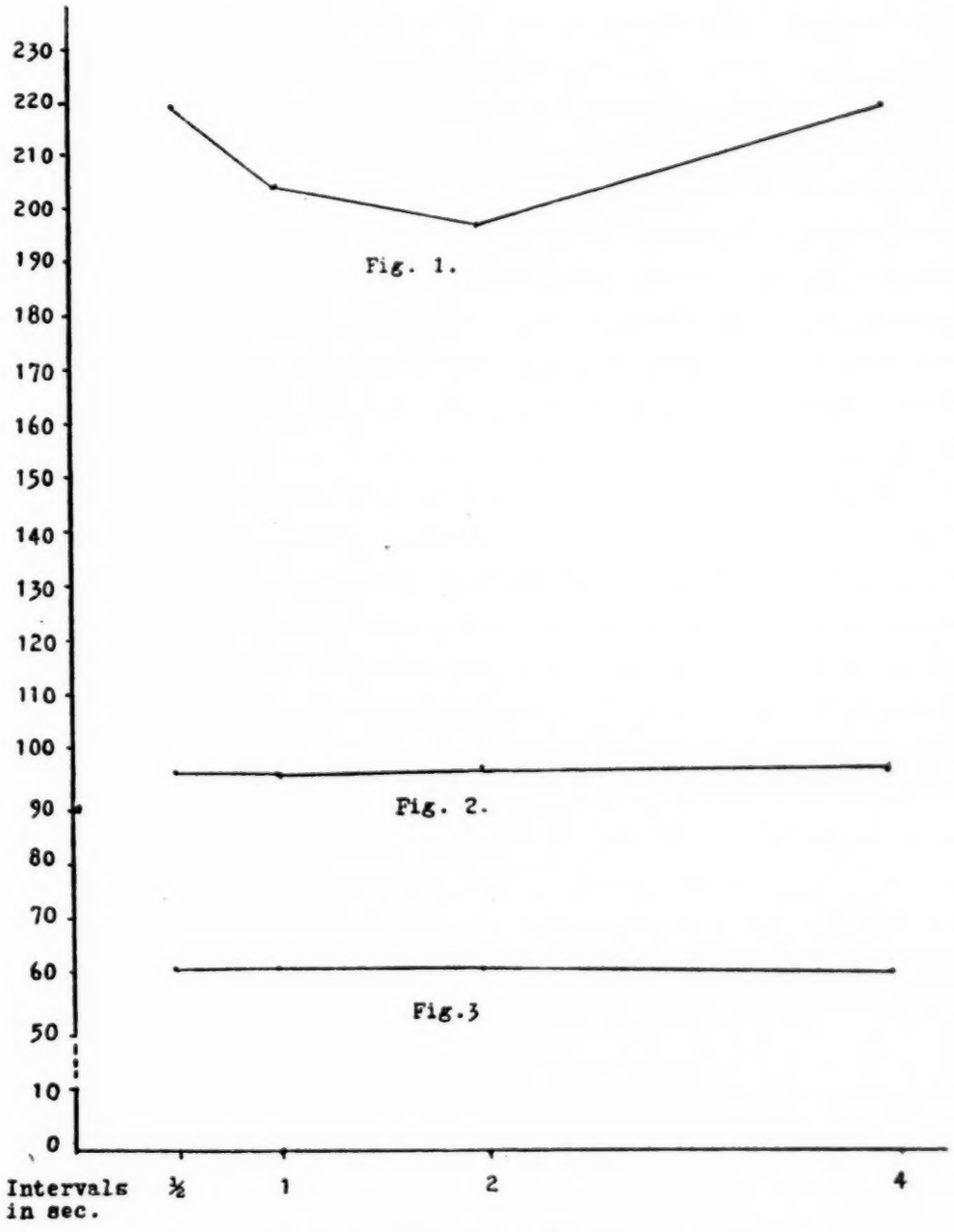

FIG. 1. Voluntary eyelid responses.
FIG. 2. Electrically stimulated reflexes.
FIG. 3. Mechanically stimulated reflexes.

as to make the 2-sec. interval, or some interval near this, the most favorable to quickness of voluntary eyelid reaction time. An examination of the mean reaction time for each of the individuals in the group (see Table 1) will reveal the fact, however, that there is a rather wide range of variation in the degree of unfavorableness of the various intervals. The reaction time was shortest at the 1/2-sec. interval for subjects No. 7, 8, and 10. The remaining seven subjects show considerable variation in reaction time at the various intervals. This is a rather significant fact to be considered in the formulation of any explanatory hypothesis. These results agree in the main with those reported by other investigators in the field of reaction time where different length intervals are used between stimuli.

Woodrow (1914) points out that it is necessary in reaction experiments to distinguish sharply between two principal procedures. The first is that in which the same preparatory interval is used a number of times in succession, the change being made in regular order from the shortest to the longest interval. The second procedure is that in which a number of preparatory intervals of widely different length are mixed in irregular order. He says that "when the first procedure is used intervals near 2-sec. are the most favorable." When the second procedure is used "little difference in reaction time occurs with the different intervals and the time obtained with each interval depends largely on the order in which the intervals are given and on the individual characteristics of the subjects." There is a noticeable general tendency, however, which he points out, for the longest reaction time to occur with the longest and with the shortest intervals of the series, especially with the shortest intervals, and for the shortest reactions to occur with the intervals of median length.

Breitwieser (1911) in a study of attention and movement in reaction time found that "an interval of 2 or 3 sec. appears to be in general the most favorable." He used 18 subjects taking ten responses at each interval from 1 to 10 sec. on each subject. He found, however, that the influence of the interval is slight when the average of all the subjects is considered,

while in the case of the individual records there was a good. deal of fluctation. Speaking of the average Breitwieser writes: "The reaction time after one interval differs but little from the reaction time after any other interval." In the case of reactions to sound the average of the group for a 2-sec. interval was 130 σ; for a 9-sec., 136 σ; and for a 10-sec., 134 σ. In the case of reactions to visual stimuli the average for the 4-sec. interval was 177 σ; for the 2-sec., 186 σ; for the 9-sec., 196 σ; and for the 10-sec., 195 σ. In both these cases the subject never knew which interval to expect.

Telford (1929) also found, using the irregular procedure, that the longest reaction time occured at the shortest and longest intervals and the shortest reaction time near the median of the series. This seems to be true irrespective of the length of the intervals up to 24 sec. (Woodrow). When the irregular method was used, Woodrow found that the most favorable interval for quickness of response was 12 sec. The reaction time found by both Woodrow and Breitwieser, when using the irregular method, was considerably longer for all intervals than that obtained when using the regular method. From these results it would seem that reaction time is influenced, in part at least by the method of procedure used.

TABLE 2

REFLEX EYELID RESPONSES TO ELECTRICAL STIMULATION

Intervals Between Stimuli	½ sec.			1 sec.			2 sec.			4 sec.		
Subject	Mean*	M.V.	V.	Mean	M.V.	V.	Mean	M.V.	V.	Mean	M.V.	V.
1	82.2	3.8	.05	81.4	2.6	.03	81.8	3.2	.04	81.0	2.0	.02
2	101.4	2.6	.03	101.8	3.4	.03	101.4	2.6	.03	102.2	2.4	.02
3	81.4	2.6	.03	81.8	3.6	.04	81.8	3.6	.04	81.4	2.6	.03
4	119.2	3.6	.03	118.6	3.2	.03	119.2	2.8	.02	118.6	2.6	.02
5	99.0	2.0	.02	98.2	3.2	.03	98.2	3.2	.03	98.6	2.6	.02
6	115.4	7.6	.07	113.2	9.0	.08	116.8	6.2	.05	114.2	8.2	.07
7	81.0	2.0	.02	80.0	1.4	.02	82.0	3.8	.05	81.0	2.2	.03
8	90.0	10.4	.12	90.4	10.6	.12	91.0	10.6	.12	90.8	11.4	.12
9	103.8	8.6	.08	103.2	6.4	.06	103.8	8.2	.08	103.2	7.4	.07
10	97.6	4.4	.04	97.2	4.8	.05	97.2	4.8	.05	97.2	4.8	.05
Average of all S's...	97.1	4.8	.05	96.6	4.8	.05	97.3	4.9	.05	96.8	4.6	.05
P.E.....	1.28			1.28			1.31			1.19		

* Each mean for the several individuals was found from 56 responses.

Electrically Stimulated Reflexes.—Table 2 shows the results for each individual and also for the group, in terms of the mean reaction time at each of the four intervals for the reflex eyelid response to electrical stimulation. The mean variation and the coefficient of variability are also shown for each individual as well as for the group. There is very little if any indication here that any one interval is more favorable to quickness of response than any other interval. This can readily be seen from the average of the group and also from the graphical representation of the same results in Fig. 2.

The method of electrical stimulation was used as a possible check on the phenomenon which has been generally found in voluntary reaction time with various length intervals between stimuli. The point of inquiry here was this: will the reflex-eyelid response, when stimulated electrically, show the same phenomenon as that of the voluntary, given the same intervals between stimuli? It seems evident from these results that whatever it is that operates to determine the optimal period or interval for voluntary responses, does not operate in the same way with respect to the electrically stimulated reflexes. If the refractory phase of the lid reflex lasts for as long as 3 sec., as Dodge (1927) has suggested, and if the optimal interval of response for voluntary and associative processes is determined by the refractory phase as Telford (1929) has suggested, then it would seem that one should expect to get comparable results from the reflex and the voluntary eyelid responses by the method here used. That this is not the case may be seen clearly from a comparison of the composite curve of the voluntary responses (Fig. 1) with that of the reflexes as shown in Fig. 2, as well as by a comparison of the averages of the several individuals on the voluntary and reflex responses (Tables 1 and 2).

Mechanically Stimulated Reflexes.—Table 3 shows the results obtained by the method of mechanical stimulation, which has already been described. It was not possible to get comparable records on subject No. 4 and 7. The other eight subjects of the original group were used in this experiment and they are designated by the same numbers as those used in the

TABLE 3

REFLEX EYELID RESPONSES TO MECHANICAL STIMULATION

Intervals Between Stimuli	½ sec.			1 sec.			2 sec.			4 sec.		
Subject	Mean*	M.V.	V.	Mean	M.V.	V.	Mean	M.V.	V.	Mean	M.V.	V.
1	57.4	1.2	.02	59.4	1.2	.02	59.4	1.2	.02	59.4	1.2	.02
2	70.0	10.0	.14	69.2	10.0	.16	68.2	9.8	.14	72.2	9.6	.13
3	65.0	9.4	.14	64.4	8.8	.12	63.8	6.6	.10	62.2	7.0	.11
5	60.0	2.2	.04	59.4	3.2	.05	59.4	2.2	.03	58.8	2.6	.04
6	57.2	4.8	.08	57.6	4.4	.07	57.2	4.8	.08	57.2	4.8	.08
8	48.8	9.8	.20	48.8	9.8	.20	48.8	9.8	.20	48.8	9.8	.20
9	61.6	2.0	.03	61.2	2.2	.03	61.2	2.2	.03	60.6	1.2	.02
10	60.0	1.2	.02	60.0	1.2	.02	59.4	2.2	.03	54.4	1.2	.02
Average of all S's...	60.6	5.1	.08	60.0	5.1	.08	59.7	4.8	.08	59.2	7.7	.08
P.E.....	1.45			1.45			1.40			2.03		

* Each mean for the several individuals was found from 36 responses.

other two experiments. The results for the mechanically stimulated reflexes are essentially the same, with respect to the effect of the length of the interval on the time of response, as those obtained by the method of electrical stimulation. These results are also shown graphically in Fig. 3. It will be observed here, as in Fig. 2 for the electrically stimulated reflexes, that when the points representing the various intervals are connected they give practically a straight line. This would seem to indicate that, so far as the average of the group is concerned, there is little evidence that the length of interval between stimuli effect the reaction time for the reflex lid response.

There are, however, some striking differences between the results obtained by the electrical and the mechanical method of stimulation of the lid reflex in other respects. For convenience of comparison a summary of Tables 2 and 3 is shown in Table 4. From this table it will be seen that the electrically stimulated reflexes are considerably longer and less variable than the mechanically stimulated reflexes. It is rather difficult to explain the difference in latency, of the lid reflex, obtained by the two methods of stimulation. The mechanically

TABLE 4

A Comparison of Electrically and Mechanically Stimulated Eyelid Reflexes

Intervals Between Stimuli	½ sec.			1 sec.			2 sec.			4 sec.		
	Mean	P.E.	V.	Mean	P.E.	V.	Mean	P.E.	V.	Mean	P.E.	V.
Electrically stimulated.....	97.1	1.28	.05	96.6	1.28	.05	97.3	1.31	.05	96.8	1.19	.05
Mechanically stimulated.....	60.6	1.45	.08	60.0	1.45	.08	59.7	1.40	.08	59.2	2.03	.08

stimulated reflex is probably more nearly the 'true' protective reflex. Ladd and Woodworth (1911) in commenting on the advantages of certain reflexes over others make the following statement: "As a rule, protective reflexes have the advantage over all others p. 173." The eyelid reflex obtained by the method of electrical stimulation would probably not be considered as a normal protective reflex, in the sense of having adaptive value for the organism. This may, account, in part, for the fact that the latency of the mechanically stimulated reflex is shorter than that of the electrically stimulated reflex. Since electrical stimuli are not common in nature there has been no chance for adaptation to evolve in the organism receptors appropriate for such stimuli (Sherrington, 1906). This, however, is not a point to be settled by speculation but one which should be subjected to carefully controlled experimentation.

The number of subjects used in this experiment was too small for correlations to mean very much. However, it seemed worth while to show the inter-correlations between the several pairs of intervals of the voluntary responses and also of the electrically and the mechanically stimulated reflexes. The correlations were also obtained between the voluntary responses and the electrically and mechanically stimulated reflexes at the various intervals, and also between the two types of reflexes (electrically and mechanically stimulated). Table 5 shows the inter-correlations between the several pairs of time intervals for the voluntary responses, and for the electrically and mechanically stimulated reflexes. These

TABLE 5

CORRELATIONS BETWEEN THE VARIOUS INTERVALS FOR THE VOLUNTARY RESPONSES AND FOR THE ELECTRICALLY AND MECHANICALLY STIMULATED REFLEXES

Voluntary Responses $N = 10$		Electrically Stimulated Reflexes $N = 10$		Mechanically Stimulated Reflexes $N = 8$	
r ½1	.78 ± .08	r ½1	.99 ± .01	r ½1	.77 ± .10
r ½2	.73 ± .10	r ½2	.96 ± .02	r ½2	.73 ± .12
r ½4	.67 ± .12	r ½4	.98 ± .01	r ½4	.67 ± .13
r 12	.88 ± .05	r 12	.96 ± .02	r 12	.88 ± .06
r 14	.89 ± .05	r 14	.99 ± .01	r 14	.89 ± .05
r 24	.94 ± .02	r 24	.97 ± .01	r 24	.94 ± .03

correlations would seem to indicate, on the whole, a high degree of reliability from one interval to another for the three types of responses measured.

TABLE 6

CORRELATIONS BETWEEN ELECTRICALLY AND MECHANICALLY STIMULATED REFLEXES AND BETWEEN EACH OF THESE AND VOLUNTARY RESPONSES

Intervals Between Stimuli	½ sec.	1 sec.	2 sec.	4 sec.
Mechanical and electrical reflexes ($N = 8$)	r −.01±.24	r .08±.24	r −.10±.24	r .05±.24
Mechanical reflex and voluntary responses ($N = 8$)	−.11±.24	−.04±.24	−.10±.24	−.38±.21
Electrical reflex and voluntary responses ($N = 10$)	.04±.22	−.14±.22	.05±.22	−.19±.14

Table 6 shows the correlations between the electrically and mechanically stimulated reflexes at each of the four intervals, and also between these two types of reflexes and the voluntary responses at the various intervals. These correlations would seem to indicate that the response latency of the eyelid reflex, as obtained by the electrical and mechanical methods of stimulation, is not dependent on the same or correlated factors. There is likewise little indication of any relationship between the voluntary reaction time and the reflex latency of the eyelid responses.

SUMMARY AND CONCLUSIONS

In this study an attempt was made to determine the differential reaction time of the reflex and voluntary eyelid responses as dependent upon the interval between the various

stimuli. An apparatus was devised for giving the serial stimuli (at the proper interval and for recording the responses). Fifty-six responses were taken at each of the four intervals, $\frac{1}{2}$, 1, 2, and 4 sec., on each of ten subjects on voluntary responses and on electrically stimulated reflexes. The stimuli were given serially and according to a prearranged chance order as to temporal period. Fifty-six reactions were taken in a series with approximately 30 sec. rest between each series, four such series of voluntary and four of reflex responses being taken at the same sitting. Eight of the same ten subjects were taken through a second experiment in which the reflexes were obtained by a method of mechanical stimulation. Thirty-six responses were taken at each of the four intervals, the method being the same as that in the first experiment, except that no voluntary responses were required. From the data obtained the following points were noted.

1. The 2-sec. interval is the most favorable to quickness of response in the case of voluntary eyelid reaction when the entire group is considered. There is, however, considerable individual variation with respect to the influence of the various intervals on the quickness of reaction. For three out of the ten subjects, the quickest reactions were obtained at the $\frac{1}{2}$-sec. interval.

2. There is little evidence that the length of the interval between stimuli (within the range here investigated) has any appreciable influence on the speed of reflex action, when the entire group is considered. This is true both for the electrically and the mechanically stimulated reflexes.

3. The inter-correlations between the various intervals of the voluntary responses and also between the electrically and mechanically stimulated reflexes are very high, indicating a high degree of reliability.

4. The very low correlations between the reflexes obtained by the mechanical and those by the electrical and between each of these and the voluntary responses indicate that the factors operating to determine the quickness of response function independently with respect to these various conditions.

5. A rather marked difference between the latency of the

reflex, obtained by the two methods of stimulation (electrical and mechanical), was found.

This study has suggested a number of problems which seem to the writer to be well worth investigating.

1. The cause of the difference in latency of the lid reflex obtained by different methods of stimulation.

2. The effect of shorter and longer intervals, than those used in this study, on the reaction time of voluntary and reflex eyelid-responses.

3. The effect of other methods of stimulation of both the reflex and the voluntary responses, such as flashes of light, puffs of air, sharp sounds, etc.

4. The effect of the procedure used, regular or irregular method of stimulation, on the voluntary and also on the reflex responses at various intervals between stimuli.

5. The effect of inhibition and facilitation on both kinds of responses at various intervals.

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AN EXPERIMENTAL STUDY OF THE EFFECT OF LANGUAGE ON THE REPRODUCTION OF VISUALLY PERCEIVED FORM

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I

History and Introduction

The experiments reported in this paper are part of a study of the conditions which affect the reproduction of visually perceived form. Previous investigators such as G. E. Müller,[1] F. Wulf,[2] and J. J. Gibson [3] have pointed out various factors which are important in bringing about the changes that occur in reproduced forms when they are compared with the forms as originally presented.

In the present study an effort has been made to control by experimental means the nature of the change in form. The directive agency used was language, or, more precisely, those processes of the organism that are initiated by language.

Historically, Müller treats of the changes that take place after the passage of time in the reproduction of perceived forms in terms which include such concepts as 'convergence' or 'blurring' of the characteristic features of patterns.[4]

F. Wulf criticizes this view and proposes, on the basis of experimental study, to describe the observed changes in terms of such specific tendencies as 'sharpening,' 'levelling' and what may be termed the 'equilibrium tendency' in the structure. He remarks, however, that in some instances his subjects spontaneously identified the presented forms with

[1] Müller, G. E., Zur Analyse der Gedächtnistätigkeit und des Vorstellungsverlaufes, III. Teil, *Zeitschrift für Psychologie*, Ergänzungsband, 1913, 8, 1–567.

[2] Wulf, F., Über die Veränderung von Vorstellungen (Gedächtnis und Gestalt) (Beiträge zur Psychologie der Gestalt), *Psychologische Forschung*, 1921, 1, 333–373.

[3] Gibson, J. J., The reproduction of visually perceived forms, *J. Exper. Psychol.*, 1929, 12, 1–39.

[4] Müller, *op. cit.*, pp. 505 ff.

different phenomenal objects. This identification, at least in his report of the experiments, involves the *linguistic* naming of the objects, and this naming appears to have been important in the production of the reproduced forms.[5]

Gibson, in a more elaborate experimental study of the problem, confirms in certain respects the work of Wulf, although he carries the analysis of factors in the reproduced forms beyond the point reached by Wulf. Gibson asserts that visual forms are often changed to agree with familiar objects that have 'previously been associated with the figure in consciousness.'[6] He also alleges that a change occurring in reproduction seems often to be determined by 'cues from a verbal analysis which was made of the forms during perception.'[7] He adds, "In general, the nature of a change found in the reproduction depends upon the manner in which the figure was apprehended," for example as 'irregular' and 'Gothic' in appearance.[8] These conclusions were based by Gibson upon the result of a study of the drawings and introspective reports of subjects who had perceived certain visual patterns used in his investigation. In Gibson's study no special experimental determination by language of the nature of these perceptions was attempted.

II

Specific Problem and Methods of Experimentation

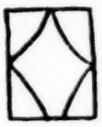
In the investigation here reported an effort was made to direct experimentally the changes in the reproduction of visually perceived form by the use of language. One set of twelve relatively ambiguous figures was prepared. (See Chart I.) Two names were assigned to each of these figures (Word List I and Word List II). The same visual figure was presented to all subjects, but one list of names was given to the figures when they were presented to one group of subjects, and the other list of names was given to the figures when they were presented to a second group of subjects. A small

[5] Wulf, *op. cit.*, pp. 347 ff.

[6] Gibson, *op. cit.*, p. 39.

[7] Ibid.

[8] Gibson, *op. cit.*, p. 16 f., and p. 36.

WORD LIST - I	STIMULUS FIGURES	WORD LIST - II
CURTAINS IN A WINDOW		DIAMOND IN A RECTANGLE
BOTTLE		STIRRUP
CRESCENT MOON		LETTER "C"
BEE HIVE		HAT
EYE GLASSES		DUMBBELLS
SEVEN		FOUR
SHIP'S WHEEL		SUN
HOUR GLASS		TABLE
KIDNEY BEAN		CANOE
PINE TREE		TROWEL
GUN		BROOM
TWO		KIGHT

control group was also used to whom the forms were presented without the assignment of any name.

The apparatus used in presenting the visual forms was a modification of the Ranschburg memory apparatus, similar to that described by Gibson.[9] The twelve stimulus-figures were drawn in black upon a white cardboard disk 19 cm in diameter. The disk was divided into 30 sectors and a figure was drawn upon every other sector. At the end of the series a space of 7 empty sectors occurred before the series repeated itself. The exposure apparatus was operated by an electrically activated pendulum. The experimenter sat at one side of the table on which the apparatus was placed, and the subject at the other side, where he could conveniently see the exposure apparatus.

By twice listening to the reading of a set of directions, the subjects were first informed that they would be shown a set of figures, and that they were to reproduce them, after the series was over, as accurately as possible, but in any order.

In any given experimental setting the apparatus was then started, and while an empty space was shown in the window of the Ranschburg apparatus, the experimenter said, "The next figure resembles . . . ." (giving one of the two names of the figure next to appear). These names were divided into two lists, I and II, respectively, as shown in Fig. 1.

As noted above, after each presentation of the total list of figures the subject was required to reproduce as accurately as possible all of the figures that he had just seen. If a recognizable representation of each figure was not given, the list was then shown again. This was repeated until a recognizable reproduction of all twelve figures was secured. The number of trials required was between 2 and 8, with an average of 3 trials. The small control group working without names required an average of 4 trials. Any verbal report volunteered by the subject in response to the question, "Will you tell me how you performed this task?" was noted down.

List I was given to 48 subjects, and List II to 38 subjects. As a check upon the naming procedure as already noted, the

[9] Ibid., p. 6.

series of visual forms was presented without names, that is, according to Gibson's technique, to 9 subjects. All subjects were college students or college teachers. Sixty of the subjects were women and 35 men. The sexes were approximately evenly divided between the two experimental groups. Altogether 3576 presentations of separate figures were given, and of this number 3051 were reproduced.

III

Results

After the experimental work had been completed, the papers on which the figures were drawn were studied, without consultation, by two of the authors. The figures were then independently rated upon the following five-degree rating scale:

Quality Step **1**.—This group included all figures that were normal or approximately perfectly reproduced.

Quality Step **2**.—This group included all figures with very slight changes from the original. Here were included figures which merely showed slight shortening or lengthening of lines, slight changes in curves or angles, or slight changes in the proportion of one part of the figure in relation to some other part of the figure.

Quality Step **3**.—This group included all figures showing a noticeable change in the original figure, but which did not mark a complete distortion. Here were included figures showing a rather marked lengthening or shortening of lines, a clearly noticeable change in curves or angles, or a noticeable change in proportion. These figures were in all cases, however, still quite satisfactory reproductions of the original.

Quality Step **4**.—This group included all figures showing marked changes such as additions or omissions, and marked changes in proportion. The figures in this group, while still somewhat resembling the original, were changed considerably from it.

Quality Step **5**.—This group included figures which were almost completely changed from the original. Here were included inverted figures, and those hardly recognizable in relation to the stimulus-figure.

The basis of rating is inadequately described in the brief verbal description given above. An absolute alteration or addition in measured line might cause one figure to be put in Group 2, while a simpler change would cause it to be put in Group 3 or even in Group 4. Thus an added line in the 'sun' or 'ship's wheel' figure was much less important than an added line in the letter 'C' or 'crescent moon' figure. The rating was done independently, and at the time of rating no reference was made to the particular associated word that had been given with the stimulus-form in question. When the judgment of the two raters differed the reasons were discussed, and if a conclusion could not be reached the choice of a third judge, who was also familiar with the rating scale, was accepted. There were very few of these contested decisions.[10] The numerical result of this rating procedure is shown in Table I which presents the numbers of reproductions falling in each of the five quality steps noted above.

TABLE I

Group	Number of Reproductions
1	26
2	285
3	1011
4	1268
5	905

[10] The authors are aware of the intrinsic shortcomings of all qualitative rating schemes, and of the fact that the rating procedures employed in this experiment are theoretically open to improvement. The plan of rating used here seemed, however, to be the best device available because of the nature of the data. It can be asserted that those concerned in the experiment felt a greater satisfaction in the result of this rating after it had been performed than had been anticipated before the rating was done. It may be pointed out that the method here used, in spite of all its shortcomings, is less dependent upon one personal opinion than that used in any of the earlier studies noted in the historical introduction to this paper. There are, of course, many methods for attempting to quantify roughly a qualitative series by rating. A number of these methods are dependent upon the training of the one who is to do the rating. This is notably true in much mental testing as, for example, in the Binet-Simon 'Ball and Field' test (*Cf.* Terman, L. M., *The Measurement of Intelligence*, p. 211). In this test there is seldom any difference in opinion in regard to the type of performance of the test when the rating is done by experienced examiners. Much of the success of rating depends upon the suitable training of the 'raters' and the possibility of immediately comparing the item under consideration in a qualitative series. These two conditions were met in the present experiment (*Cf.* Dearborn, W. F., *Intelligence Tests*, pp. 8 f, and Munroe, W. S., *An Introduction to the Theory of Educational Measurement*, pp. 133–144).

For the purposes of the present study it was decided first to study the figures in Group 5, for these figures by definition showed the greatest amount of change from the stimulus-figure. Subsequent study, not recorded here, of Quality Groups 2, 3, and 4 showed similar relationships but in a less marked degree. It seemed to the present authors that if most of the figures in Quality Group 5 could be shown to have varied from the stimulus-figure without showing any constant relationship to the typical form of the objects represented by the concomitantly presented word of either list, then the conclusion must be accepted that the associated verbal stimulus was unimportant in the modification of form as shown in the reproduction of visual pattern. On the other hand, if the figure in Quality Group 5 appeared more like the object represented by the concomitantly presented word, the assumption of the influence of language would be justified. The observation of this relationship should also throw some light upon the question left unsolved by Gibson as to whether the changes that he observed were caused by the influence of past experience upon the perception or memory of form, or whether evidence can be found that unequivocally shows that the changes were caused, as alleged by Wulf, by the nature of the *structure* of the perceived form itself.

A study of the nature of the variations in Group 5 showed marked differences between different figures. These differences again required rating, which was carried out as before. In Table II the judged amount of influence of the two lists is given. It thus appears that of the 905 figures in Group 5 approximately 74 percent were like what may be termed *the visual representation of the figure named* in List I, and 73 percent were like the visual representation of the figure named in List II. A comparatively few cases of the control group to whom no verbal associate was given showed a resemblance to the visual representation of either of the named figures, or only 45 percent. Chart II shows some selected examples of pronounced modification.

It may be seen by an inspection of Table II that all of the figures were not truly ambiguous to the various subjects. It

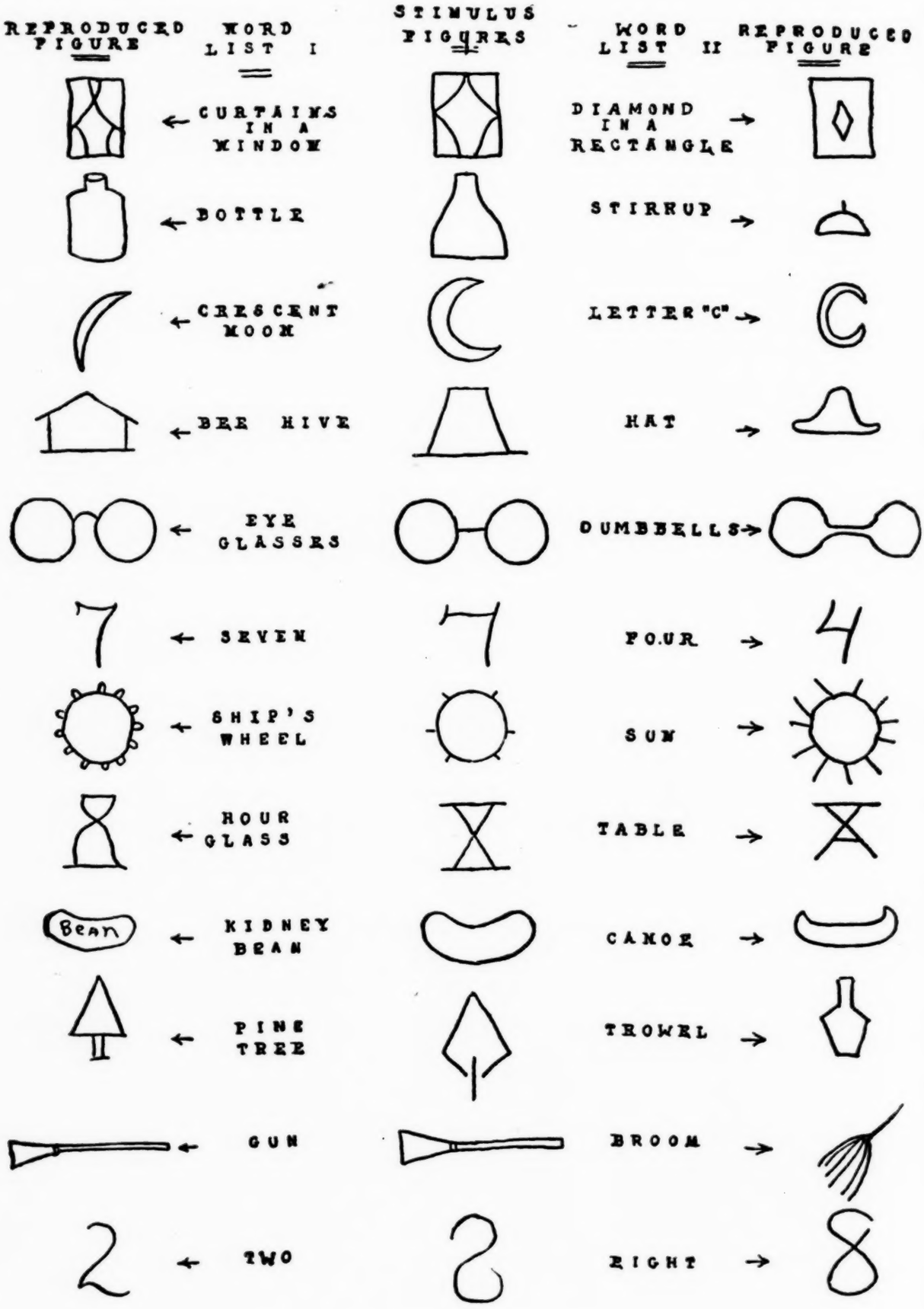

REPRODUCED FIGURE
WORD LIST I
STIMULUS FIGURES
WORD LIST II
REPRODUCED FIGURE
CURTAINS IN A WINDOW
DIAMOND IN A RECTANGLE
BOTTLE
STIRRUP
CRESCENT MOON
LETTER "C"
BEE HIVE
HAT
EYE GLASSES
DUMBBELLS
SEVEN
FOUR
SHIP'S WHEEL
SUN
HOUR GLASS
TABLE
Bean
KIDNEY BEAN
CANOE
PINE TREE
TROWEL
GUN
BROOM
TWO
RIGHT

TABLE II

Figure	Percent like Figure Named	
	List I	List II
1	47	78
2	100	69
3	65	48
4	69	75
5	45	81
6	87	94
7	54	47
8	83	100
19	90	63
10	86	100
11	76	85
12	87	40
Total percent	74	73

may be that some verbal names were therefore much more effective than others. In some cases, even if the subjects were representing the object named rather than the form visually perceived, there would be little differentiation in the end result. The 'stirrup' and 'bottle' figure was an example of such a case. If the experiments are repeated, every effort should be made to avoid figure-name constellations of the sort represented by the stirrup-bottle figure.

In spite of these difficulties which were exposed in the course of experimentation, and in spite of the fundamental objections to the rating procedures employed in the experiment, it seems to the authors, on the basis of the examination of the forms in Groups 2, 3, and 4, as well as those considered above, that it may be said with assurance that naming a form immediately before it is visually presented may in many cases change the manner in which it will be reproduced. Besides the major conclusions just noted, the results of the experiment in many ways confirm the conclusions already published by Gibson, and in certain minor respects differ from these conclusions.

Contrary to the assertion of Wulf and Gibson, it was found in certain instances that straight lines were reproduced as curved. An example of this fact is seen in the 'table' and 'hour-glass' figure. In several instances this 'straightline' figure was reproduced in curved lines. Many examples of what Gibson terms 'figure assimilation' were observed.

In final conclusion, therefore, it may be said that the present experiment tends to confirm the observations of previous experimenters in this field, and to show that, to some extent at least, the reproduction of forms may be determined by the nature of words presented orally to subjects at the time that they are first perceiving specific visual forms.

IV

Theoretical Conclusions

The explanations offered by the previous investigators in this field to account for the observed changes in the figures have differed.

Müller, from the fundamental standpoint of his particular form of associationistic psychology, has *described* the changes that occur in reproduction in terms of certain verbal principles. But behind these descriptive terms may be discovered the intention of offering, as for example in the concept of 'affective change,' [11] an explanation of the psychological origin of the observed experience.

Wulf, on the other hand, from the standpoint of Gestalt psychology,—It will be remembered that his experiment was entitled 'A Contribution to the Psychology of Gestalt.'—turns from the older and, in one sense at least, explanatory psychology of associationism, to a more purely descriptive psychology. The changes that he treats are included under the heading '*der Gesetz der Pregnance.*' [12] According to this view all patterns tend to become 'as good as possible.' That is, they tend to achieve a greater stability and precision.[13] Köhler contends, in dealing with memorial traces, that "traces are not rigid, then; there are definite dynamical tendencies in them." [14] Köhler further, in commenting on Wulf's experiment, says in regard to reproduction, "The figures had not simply lost details at the time of graphic reproduction. The changes were much more interesting since they showed two

[11] Müller, *op. cit.*, p. 377 ff.

[12] Köhler, W., *Die physischen Gestalten in Ruhe und im stationären Zustand*, p. 259.

[13] *Cf.* Ogden, R., *Psychology in Education*, p. 238.

[14] Köhler, W., *Gestalt Psychology*, p. 309.

opposite directions: In reproduction the figures were either more regular than the original ones, or some traits which might be taken as characteristic of their organization were considerably exaggerated in the drawings. . . . Therefore, in both cases the change seemed to produce an approach toward something like an extreme type or the ideal of the first organization." [15] No explanation of this process is given, however, save that it is somehow inherent in the structure. In this case, as Gibson well says on the basis of Rignano's criticism, Wulf is evidently not speaking of physical form, but of phenomenal or conceptual form.[16] According to the Gestalt psychologist, then, a configuration is dynamic and is governed by the laws of its own structure. Gibson points out, "The issue is this: Is the change in the reproduction of a perceived form caused by the influence of past perceptions on the perception and memory of this form, or is the change caused by the nature of the form itself? No attempt is made to solve this issue." [17]

It may now be seen that the experiments in this paper were set to bear directly on this problem. In the view of the present authors, the experiments here reported tend to substantiate the view that not the visual form alone, but the method of its apprehension by the subject determines, at least in certain cases, the nature of its reproduction.

It is the belief of the present authors that psychology is not yet in a position to *explain* this process of apprehension with assurance. As Wulf himself points out,[18] Wundt's concept of assimilative perception might be used as an explanatory principle. Similarly, the results can be explained in

[15] Ibid., p. 310.

[16] Gibson, *op. cit.*, p. 34; Rignano, E., The psychological theory of form, *Psychol. Rev.*, 1928, 35, p. 128.

[17] Gibson, *op. cit.*, p. 35. Dr. Gibson informs me in a private communication that Dr. Koffka, under whose direction the article by Dr. Wulf was written, would prefer, instead of the phrase 'change caused by the nature of the form itself', some statement emphasizing the fact that in his opinion the change was caused by dynamic processes within the physiological correlate of the percept. The writers wish to thank Dr. Gibson for making this suggestion and for other suggestions which have been incorporated in this paper.

[18] Wulf, *op. cit.*, p. 367.

terms of the Herbaritian apperception,[19] and, to choose but a single additional example, by Witmer's pre-perception.[20]

A so-called 'dynamic view' is favored by Gibson. This view holds that assimilation in perception is not caused by a fusion of images, nor yet by the influence of one configuration upon another, but by the turning of a new perceptual process into earlier channels of perceptual activity.[21] This view is not unlike, in certain respects, the engram theory of Semon, if that theory were to be applied to the present problem.[22]

To the present writers such theories seem interesting and important but possibly premature. Further experimental work in terms of careful introspection must be done if the exact nature of the processes of apprehension, reproduction, and recognition as seen in this experiment, are to be understood. On the basis of introspective reports secured in the present experiment, it seems probable that great individual differences will present themselves. In science, in general, a complete description can only be given when all of the terms of the so-called 'causal' series are known. When the theoretical psychologist is forced to jump from the stimulus object to the result of objective response, namely, in this case, the reproduced drawing, error is likely to creep in. A suggestion of some of the stages which may lie between these two extremes may be presented here. It should be understood, however, that this attempt is given in the most tentative terms.

1. When a meaningful word is heard by an individual, some process within his organism is initiated which presumably includes receptor activity, neural activity, and effector response. This activity includes the activity of those processes which are held by some psychologists to be the correlates of the introspectively known states of imagery or symbolic representation. These physiological processes are, if the

[19] Boring, E. G., *A History of Experimental Psychology*, p. 245.

[20] *Cf.* "A perception may be determined by the association of an anticipating mental image or idea of the object,—*i.e.*, by pre-perception." Witmer, L., *Analytical Psychology*, p. 4.

[21] Gibson, *op. cit.*, p. 38.

[22] Semon, R., *Mnemic Psychology*, pp. 169–197.

theory be accepted, in part the result of present sensory stimulation, and in part the result of the eduction [23] of activities and experiences that would not be as they are save for the past experience of the organism.

2. When a visual (or, indeed, any other sensory) pattern is perceived by an individual, it may likewise be assumed that certain processes within the organism are initiated which include activities similar to those considered above, but which are in some measure correlated with the given visual experiences.

3. The present objective experimental results seem to show that in many cases the recall of a visually perceived form is altered by the fact that a particular word is said immediately before the visual presentation of the form.

4. Without the use of additional terms, therefore, it seems that if a subject has just heard, for example, the word 'eye glass,' certain processes in his organism have been started that initiate certain processes which are possible because of the past experience of that individual with *eye glasses* as words and as objects. If, while these processes are in progress, a figure of two visual circles connected by a line is presented to the subject, this figure may later be reproduced in a different manner than as if the processes present in the individual at the time of the same visual presentation had been evoked by the word 'dumbbell.' In other words, without recourse to any elaborate theory, one who wishes to make an empirical statement of fact may say: If a verbal stimulus-form and a visual stimulus-form are presented to a subject in certain temporal relationships, the processes in question may be modified, or rather a new total process may result, which is in certain respects unlike either of the previous sets of processes. On subsequent arousal by any 'part' stimulus the 'reproduction' is thus a complexly determined total, and not either of its component processes.[24]

[23] *Cf.* Spearman, C., *The Nature of Intelligence and the Principles of Cognition*, pp. 70 f.

[24] *Cf.* Hollingworth, H. L., *Psychology: Its Facts and Principles*, pp. 33–49, for a treatment of the general laws of redintegration.

Thus, as is so often the case, phenomena that are said to be explained in the verbal terms of the Configurational theory may at least tentatively be described in terms of a dynamically considered process of association.[25]

[25] For an outline statement of this view see Warren, H. C., and Carmichael, L., *Elements of Human Psychology*, pp. 176–184.

(Manuscript received December 6, 1930)

THE RELATION OF STUTTERING AND ALCOHOL TO CERTAIN TREMOR RATES[1]

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The occurrence of tremors in healthy persons was recognized as early as 1880 by Debove and Baudet (1). In 1896 Eschner (2) well established the truth of this observation. The most commonly recorded rate is 8 to 12 tremors per second. Neurophysiologists (3), (4), (5), (6), and (7), assign this tremor to the motor cortex. Athough we do not now agree with his statement in its entirety Peterson (8) has said "it is probable that all tremors are a modification of the rhythmic discharges from the cortex, which as is well known takes place at the rate of ten in a second." In a recent paper Travis (9) showed an absence of this tremor rate in the affected side in complete hemiplegia. This indicated that the source of this tremor rate has been correctly attributed to the cerebral cortex.

The purpose of the present study was to determine the effects of stuttering upon the rate and the extent of this tremor.

Apparatus and Method

The apparatus was that used by Travis (9). Briefly it consisted of three phonelescopes focused in the same vertical plane on Eastman standard size superspeed motion picture film. One phonelescope was used to record the tremors. To record these the fore-finger was placed directly on the membrane of the phonelescope. Into the backs of the other two phonelescopes were screwed telephonic electromagnetic receivers. One of these phonelescopes was placed in a circuit with a single dry cell battery and a make key to furnish a record of periods of overt stuttering. The other one was connected through a step down transformer (110/24) and a 2

[1] This study was done under the direction of Professor Lee Edward Travis.

m.f. condenser to a sixty cycle alternating current to record time in sixtieths of a second. The film was pulled through a film guide from a film box by a large wheel turned by hand. The various units of the apparatus were mounted separately on a thirteen inch concrete wall which extended several feet into the ground.

In order to obtain tremors from only the muscles responsible for the sustained extension of the fore-finger the hand was firmly supported at the level of the phonelescope. All tremors recorded were from the right hand. Each subject was instructed to extend his fore-finger and place it on the center of the phonelescope membrane. At an agreed command the subject was to talk of anything he wished. None recited memorized material.

Subjects

Thirteen male stutterers between the ages of 20 and 25 presenting both clonic and tonic types of stuttering served as subjects.

Results

There are three aspects of the tremor that might be observed, namely amplitude, rate and wave shape. Of these only the first two, amplitude and rate, were studied. In addition to these two aspects, consideration was given to the number of tremors appearing in equal intervals of time for the three conditions of the experiment, silence, free speech, and stuttering. Amplitude was determined by measuring the heights of tremors on a scale of equidistantly spaced horizontal lines. The units of the scale were arbitrarily chosen and represent a distance a little greater than 1 mm. These reported heights are not the absolute heights as any amplitude less than one was considered zero, and less than two was considered one, etc. In other words, no effort was made to estimate to fractions of a division of the scale. Furthermore, as will be seen in the third column of Table II tremors often failed entirely to appear during stuttering. On the basis of the rate of the tremors present during the stuttering period, the number of tremors, which would have appeared ordinarily

in the interval for which there were no tremors, was calculated. Each tremor derived by this means was given an amplitude value of zero and averaged in with those tremors which could be read. The number of tremors for each subject was determined as the average number occurring in an interval of time which was of the same length for silence, free speech, and stuttering. All figures in Tables I and II are averages derived from between 25 to 149 readings per subject. The ratio of observed difference to probable error of difference is expressed for each comparison that is made.[2]

Table I shows the differences in amplitude and rate of tremors during silence and during free speech in the first five

TABLE I

THE EFFECT OF NORMAL SPEECH ON AMPLITUDE, RATE, AND NUMBER OF TREMORS OF A RATE OF 8–12 PER SECOND

Subject	Amplitude			Rate per Second			Number of Tremors	
	Silence	Free Speech	$\frac{O.D.}{P.E._{diff.}}$	Silence	Free Speech	$\frac{O.D.}{P.E._{diff.}}$	Silence	Free Speech
E. S.	2.3	2.5	1.4	11.8	9.8	2.5	9.0	8.0
M. S.	1.0	1.3	2.1	7.3	6.2	4.4	8.5	6.0
W. S.	2.7	2.3	2.2	7.6	6.6	2.6	7.0	6.5
R. W.	2.1	2.6	1.9	6.0	6.9	.4	9.0	9.5
S. C.	.77	.87	1.6	9.5	9.0	3.1	9.0	8.0

stutterers studied. It will be observed that the act of speaking normally has no significant effect upon the amplitude of the tremor under consideration. There is a general tendency for the tremor rate to decrease during speech, but inasmuch as this trend is significant in only two of the five subjects, not much confidence can be attached to the finding. The greatest variation in the number of tremors per unit of time in the two situations is one and one-half tremors. This variation is quite insignificant since a rate difference of one tremor per second is found to be unreliable in the same subject. Table II gives the differences in amplitude, rate per second, and number of tremors found between free speech and

[2] This ratio should be three or more to be significant.

TABLE II

THE EFFECT OF STUTTERING SPEECH ON THE AMPLITUDE, RATE AND NUMBER OF TREMORS OF A RATE OF 8–12 PER SECOND

Subject	Amplitude			Rate per Second			Number of Tremors	
	Free Speech	Stuttering	O.D. / P.E.diff.	Free Speech	Stuttering	O.D. / P.E.diff.	Free Speech	Stuttering
E. S.	2.5	1.6	6.4	9.8	10.0	2.2	8.0	7.5
M. S.	1.3	.50	13.0	6.2	6.8	2.0	6.0	7.0
W. S.	2.3	1.7	4.0	6.6	7.2	1.5	6.0	4.3
R. W.	2.6	1.9	2.4	6.9	6.4	1.2	9.5	5.0
S. C.	.87	.31	8.0	9.0	9.2	1.2	8.0	4.5
S. B.	1.1	.48	6.2	8.6	8.5	.38	15.0	14.6
F. R.	3.2	1.3	5.4	6.9	8.3	6.6	7.8	7.4
P. G.	1.7	1.2	3.8	8.0	8.8	3.7	23.0	23.0
J. P.	2.9	2.0	3.4	10.5	10.3	1.1	28.0	15.0
C. C.	2.4	1.1	5.2	7.7	9.8	5.8	12.0	7.0
L. B.	3.8	1.3	5.0	8.4	8.8	1.4	9.0	9.0
P. H.	2.4	1.0	8.2	10.7	11.1	2.2	11.5	9.6
M. B.	2.1	.93	6.1	9.9	8.9	3.8	14.3	7.6

stuttering. In all cases but one, R. W., the amplitude of the tremor is significantly decreased during stuttering (Fig. 1.) The rate of tremors is significantly affected by stuttering in only four cases. Three of these show a decrease and one an increase in rate during stuttering.

The effect of stuttering upon the number of readable tremors is marked. In some subjects stuttering inhibits the appearance of tremors for over half the duration of the period studied.

EFFECT OF ALCOHOL ON TREMORS

At this point the research was extended to include the effect of alcohol upon the tremors. Dodge and Benedict (**10**) and Travis and Dorsey (**11**) have clearly shown that alcohol is a depressant to the nervous system having its first action on the higher centers. Being a depressant we wished to see what effect it would have on the tremors.

The same apparatus as previously described was used here. The alcohol used was double distilled 95 percent C. P. Alcohol.

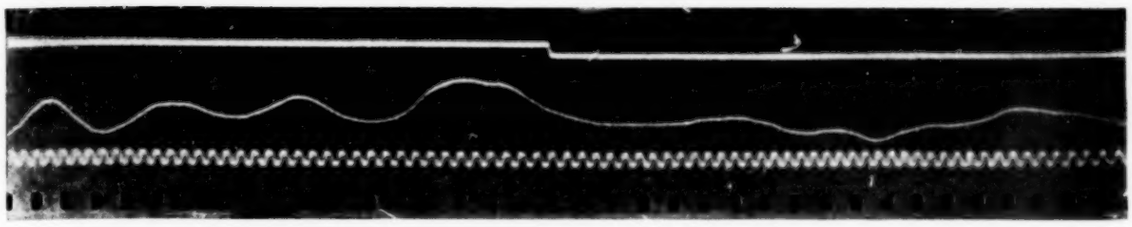

FIG. 1. A decrease in the amplitude of the tremors (8 to 12 per second) during stuttering. The break in the signal line (top) indicates the beginning of overt stuttering. In this and all subsequent figures time is in sixtieths of a second.

Subjects and Results

Six normal speaking males between the ages of 23 and 27 with varying appetites for alcohol served as subjects.

H. H., age 27, had been a constant drinker for the past five years. He drinks to intoxication two or three times a week with occasional drinks between sprees. He had had nothing to eat for nine hours prior to the experiment and had drunk to mild intoxication twenty-four hours before. 150 cc of 'near-beer' containing alternately 50 and 30 cc of alcohol was given H. H. every half hour for three hours. Thus he was given a total of 240 cc of alcohol. Tremor records were taken before every drink. After 80 cc of alcohol the tremors began to be depressed until after the entire amount of alcohol had been consumed, five hours after the experiment began, the tremors disappeared completely (Figs. 2 and 3). At this time

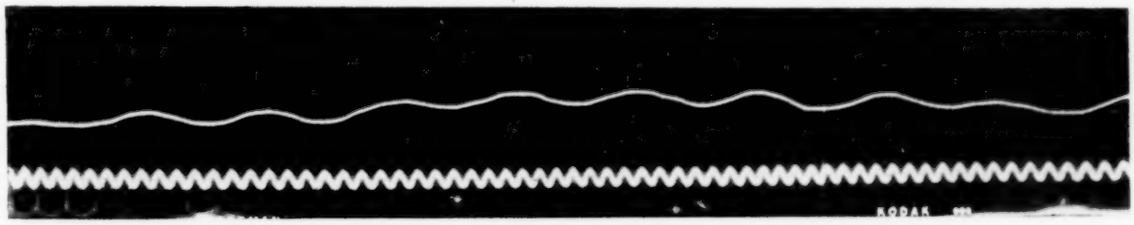

FIG. 2. Tremor record of H. H. prior to ingestion of alcohol.

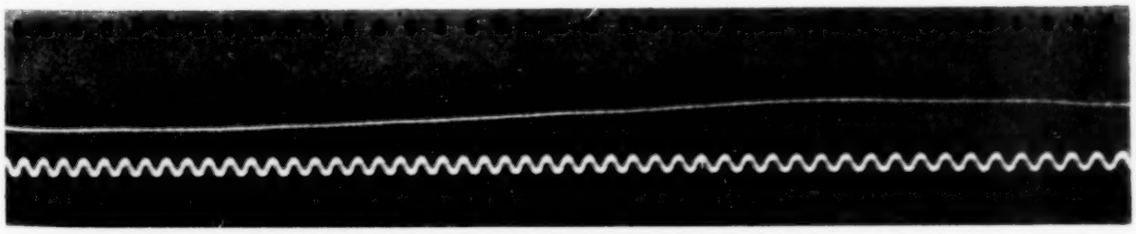

FIG. 3. Tremor record of H. H. after ingestion of 240 cc of alcohol.

the subject had all but lost voluntary control of general body movements.

R. I., age 23, had been a moderately heavy drinker for the past three years. He drank to intoxication two or three times a month with occasional drinks between times. He had eaten a light lunch four hours prior to the start of the experiment. R. I. was also given 150 cc of 'near-beer' every half hour containing alternate doses of 50 and 30 cc of alcohol. Records were taken every half hour. After 80 cc of alcohol the tremor frequency of 8 to 12 tremors per second disappeared but the tremor line became very irregular and rough and tremors of a rate of 15 to 20 per second appeared (Fig. 4).

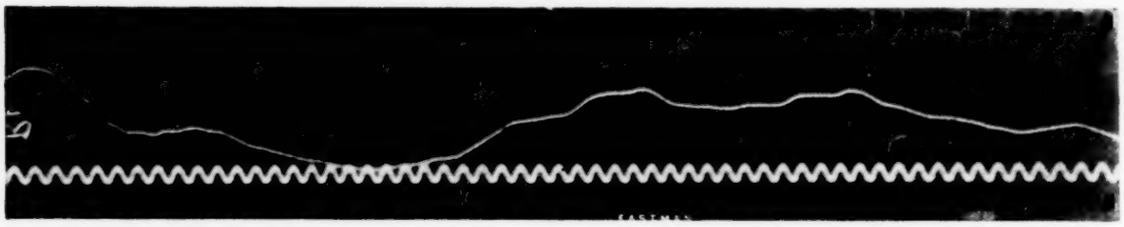

FIG. 4. Tremor record of R. I. showing tremors of a rate of 15 to 20 tremors per second.

After ingesting 130 cc of alcohol R. I. became sick and a half hour later vomited. One hour after vomiting the fast tremors (15 to 20 per second) had disappeared but the slower tremors (8 to 12 per second) had not regained their normal amplitude.

H. B., age 23, was a mild drinker. He had been intoxicated about once a month for the last two years. He had eaten a normal meal two hours and a half before the experiment began. 30 cc of alcohol were administered every half hour in 170 cc of orange flavored carbonated water. Records were taken after the ingestion of 90 and 150 cc of alcohol. The amplitude of the tremors was noticeably decreased after 90 cc of alcohol and was completely depressed after 150 cc of alcohol.

T. H., age 24, was also a mild drinker. He has been intoxicated about once a month for the past five years. He had eaten a normal meal two and a half hours before the experiment began. Every half hour 30 cc of alcohol were given in 170 cc of orange flavored carbonated water. Records were taken after the ingestion of 90 and 150 cc of alcohol. After 90 cc of alcohol, the tremors were gone. After 150 cc of alcohol

the tremors of the usual rate were still absent but a faster tremor frequency of 40 to 75 tremors per second appeared. In the third record, taken after vomiting the slower tremor was reappearing but was obscured by the faster one (Fig. 5).

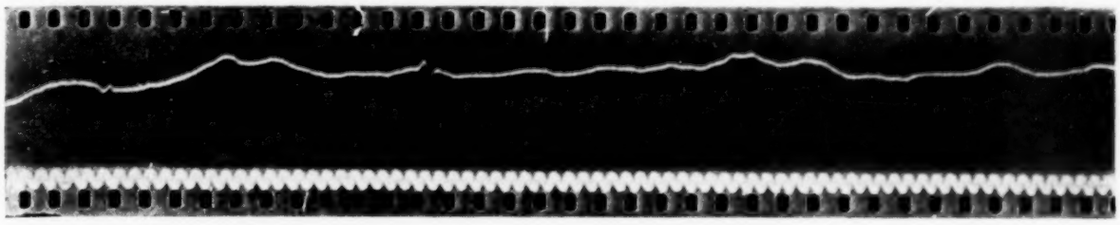

FIG. 5. Tremor record of T. H. showing tremors of a rate of 40 to 75 tremors per second.

W. T., age 26, was a very light drinker. He had drunk to intoxication only six times in his life. He had a normal meal two and one half hours before the experiment began. Thirty cc of alcohol were given every half hour in 170 cc of orange flavored carbonated water. Records were taken after 80 and 150 cc of alcohol were ingested. There was not much difference between the extent of the slower tremors in the normal records and the extent of those in the records taken after 90 cc of alcohol had been ingested. Tremors of a rate of 15 to 20 per second appeared however. The slower tremor was completely depressed after 150 cc of alcohol and a fast tremor rate, 40 to 75 tremors per second, was pronounced.

Thus in all cases it is seen that alcohol decreased the amplitude of the tremors of a rate of 8 to 12 tremors per second and in some cases introduced two new tremor rates. The first of these to appear had a rate of 15 to 20 and the other of 40 to 75 tremors per second.

EFFECT OF VOLUNTARY MOVEMENT ON TREMORS

In the course of the work thus far reported it was casually noted that gross voluntary movement brought out quite markedly the tremor rate of 40 to 75 tremors per second. The work was again enlarged to determine if any consistent difference in the occurrence of this rate could be demonstrated between stutterers and normal speakers.

Subjects and Method

The subjects, eight stutterers and nine normal speakers were all university students. Each was instructed to place his right fore finger on the center of the phonelescope diaphragm. At a command he was to slightly depress his finger and on elevating it to keep the recording beam of light as near the center of the film as possible. The hands of the subjects were not supported. All records were made during silence.

Results

Table III gives the percent of the time of occurrence of the fast tremor rate, 40 to 75 tremors per second. The percent was computed by reading the number of tremors occurring in a set interval of time. The time interval for all subjects was five seconds and the average number of gross movements in this interval for both groups was five.

TABLE III

THE PERCENTAGE OF TIME THAT THE TREMOR RATE OF 40 TO 75 TREMORS PER SECOND APPEARED IN STUTTERERS AND NORMAL SPEAKERS

Stutterers		Normal Speakers	
T	15.6	D	6.9
H	7.1	F	—
B	11.2	P	3.6
M	22.2	Pa	1.2
K	11.3	B	2.1
I	12.0	Fa	3.8
N	8.8	W	2.0
S	21.4	L	1.5
		H	1.8
Average	14.0		2.5

It will be seen in Table III that the fast tremor appeared much more frequently in the stutterer than in the normal speaker.

This greater proponderance of the fast tremor rate in the voluntary effort of the stutterer was well borne out in records taken for the first part of this report where we were not concerned with voluntary movement. When the hand was supported normal speakers rarely gave this fast rate of 40 to 75 tremors per second, but stutterers' records showed the fast

tremor very consistently whether during silence, free speech, or stuttering. Table IV shows the number of these tremors

TABLE IV

THE NUMBER OF TREMORS WITH A RATE OF 40 TO 75 PER SECOND APPEARING IN STUTTERERS' RECORDS IN HALF A SECOND

Subject	Silence	Normal Speech	Stuttering
R. W.	8	15	17
J. F.*	—	10	9
W. S.	8	7	7
C. A. C.*	—	6	11
L. B.*	—	8	16
E. R.*	—	4	7
S. C.	6	7	12
P. H.*	—	10	12
P. G.*	—	8	11
J. P.*	—	12	15
M. B.	5	7	12
Average	6.75	8.36	11.72

* No records taken during silence.

occuring in half a second in stutterers' records taken during the experimental work of the first part of this paper. It will be seen that these tremors are present under all considerations of the experiment and that their number is usually increased during stuttering.

GENERAL SUMMARY

1. Both stuttering and alcohol depress the tremors of a rate of 8 to 12 per second.

2. Alcoholic depression also causes the appearance of two other tremor rates, one 15 to 20 tremors per second and the other 40 to 75 tremors per second.

3. Voluntary movement produces a greater percentage of tremors of a rate of 40 to 75 per second in stutterers than in normal speakers. This tremor rate is more pronounced during stuttering than during silence or during free speech.

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(Manuscript received November 2, 1930)

A LABORATORY CLASS DEMONSTRATION OF THE ESTABLISHMENT OF A CONDITIONED REFLEX *

BY KEY LEE BARKLEY

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The conditioned reflex, while subjected to research in many laboratories, has not been presented except in theory to the undergraduate students of general psychology. Indeed, some teachers have supposed it too refined a technique to be demonstrable in a routine introductory course. But at North Carolina the apparatus which is described in this paper has been used to give a concrete demonstration of the establishment of a conditioned reflex in such a manner as to enable all the students in the class to observe the process. The demonstration is now given regularly as one of the experiments in the general psychology laboratory.

The set-up may be built out of the ordinary bits of apparatus to be found in almost every psychological laboratory. The inductorium is the only instrument which usually might not be found in the laboratory equipment. The method used in the experiment is in general the same as that outlined by Watson in a publication some years ago.[1] The apparatus has many features like that described by Watson, but modifications and additions have been made in various ways. The chief differences are those necessary to make the operations visible to a large group of observers at a single time and to control the movements of the subject. The reflex to be conditioned was the finger retraction to the sound of a bell.

* Reported from the University of North Carolina Psychology Laboratory.

[1] Watson, J. B., The place of the conditioned reflex in psychology, *The Psychological Review*, 1916, 23, 89–116. Mentioned also in his text, *Psychology from the Standpoint of a Behaviorist*, Lippincott, 1924, 28–38, in J. F. Dashiell's *Fundamentals of Objective Psychology*, Houghton Mifflin Co., 1928, 173, and in Collins and Drever's *First Laboratory Guide in Psychology*, Methuen, London, pp. 61–62.

MATERIALS: Kymograph, inductorium, triple signal marker, metronome, sound-proof box, tambours, double contact key, electric bell, batteries and suitable electrodes.
CONNECTIONS: (See accompanying diagram).

The bell, the inductorium, and the metronome were all placed in separate circuits each with one of the indicators of the triple signal marker. The bell and inductorium circuits

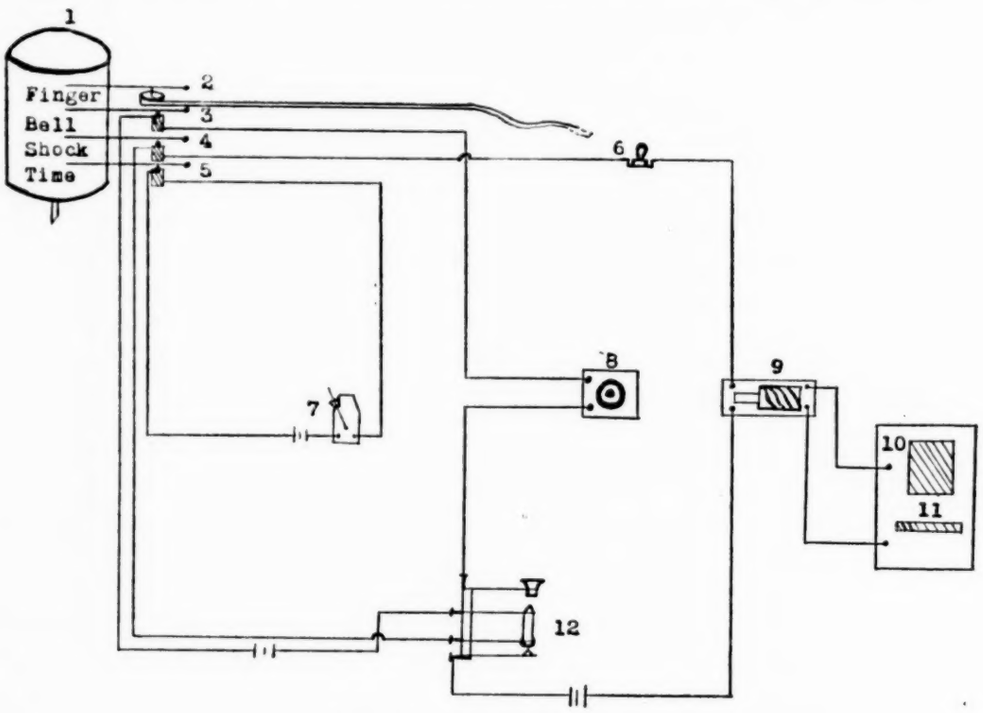

DIAGRAM OF CONNECTIONS

1. Kymograph.
2. Marey Tambour.
3, 4, 5, Markers.
6. Lamp.
7. Metronome.
8. Bell.
9. Inductorium.
10. Flat Electrode.
11. Narrow Electrode.
12. Double Contact Key.

were arranged so that they could be made and broken easily through use of a double contact key. The bell was connected through the first contact made in pressing the key, and the inductorium through the second; so that when the key was pressed lightly, only the bell circuit would be completed, but when it was pressed farther down both the bell and the shock circuits would be completed. This arrangement insured that the shock would never be given before the bell, and that the

bell and shock circuits would be completed as nearly simultaneously as possible with simple arrangements.

The metronome was used to mark time intervals of one second. These long intervals were used so that they would be easily observable to all the students in the section. The metronome had to be placed in a sound-proof box, because on some occasions the subjects were conditioned to the sound of its ticking.

The inductorium was used to increase the potency of the mild shock given the subjects and to control the amount of current which was sent through the subject. An ordinary six volt battery was used. The shock was given at the make and break of the circuit each time the vibrator of the inductorium made one complete oscillation. This oscillation was very rapid and the potency of the stimulus given was thus much increased through summation effects.

The amount of current in the primary inductorium circuit remained constant, but the amount of current in the secondary circuit could be controlled by adjusting the coil of the inductorium. The amount of current necessary to call out a response is not the same for all subjects, hence the necessity for the adjusting device. In addition, the subject tends to become adapted to a given severity of shock. This adaptation necessitates an increase in the amount of current possibly several times in the course of the experiment. In order to insure the potency of the shock and to prevent adaptation taking place near the beginning of the experiment, it is best to give a severe shock at the first trial.

As a further aid to the observers, a miniature lamp which gave a flash each time the circuit was closed was placed in the primary circuit to the inductorium.

Two electrodes were placed in the secondary circuit from the inductorium in such a way that the circuit could be completed through the hand of a subject. A broad copper electrode was placed in position for the subject to lay the palm of his hand on it. This electrode was raised about three-fourths of an inch from the table at the end towards the subject's fingers so that the hand could be placed in contact with

it without strain. A second copper electrode about one-half inch wide was placed at a proper distance from the broad electrode for the subject to lay the first joint of the middle finger on it. All parts of the narrow electrode were insulated except where the finger of the subject was to touch it. With such an arrangement the shock would be felt only in the part of the finger on the narrow electrode.

To control the retraction movements of the subject, an elbow rest was placed directly behind his elbow to keep him from jerking straight back from the point of contact, and two standards were erected one on each side of the finger to prevent side movements. The arm and hand were not otherwise restrained.

A receiving tambour with a cork saddle attached was arranged so that the saddle rested firmly on the subject's finger just back of the point at which it came into contact with the narrow electrode. This receiving tambour was connected with a Marey tambour by a column of air through a rubber tube. The indicator of the Marey tambour was fixed to make a tracing on a smoked kymograph drum. Thus the movements of the subject's finger could be translated and recorded on the drum.

Procedure

The subject was seated by the side of a table before a group of observers with his hand placed on the electrodes as indicated above. When the saddle had been adjusted and all the other parts of the apparatus made ready to start working, the following instructions were given the subject. "In the course of the experiment you will feel a mild electric shock. Sit with your eyes closed and relax as much as you can. Do not try to inhibit any reaction you tend to give in response to the stimulus and do not try in any way to anticipate the stimulus. Always return the finger to the electrode immediately if it is once removed. If there is a delay for a moment in the course of the experiment, just sit quietly; I shall tell you when the experiment is finished."

At least one and preferably four or five stimulations with the bell alone would be given to show that the subject did not

react to the ringing of the bell alone by lifting his finger. Following these stimulations with the bell alone, the usual procedure was to give about five stimulations with the shock and bell simultaneously. After each series of joint stimulations, the bell would be given alone to see if a conditioned reaction would appear. When a conditioned reaction was elicited, the bell was given alone again and continued until there was a failure of response.

In the early stages of conditioning it was found best to follow the failure of response with a series of joint stimulations with the bell and the current. In the later stages one shock was frequently sufficient to reëstablish the conditioned reaction.

Results

(See sample tracing)

The results of the experiment were shown on smoked drum tracings. These were preserved and placed under glass. In order to enable each student to have a record for study, a chart with column headings for reporting the tracings was devised.

Trial	Unconditioned Stimulus	Response	Conditioned Stimulus	Response

The directions were as given below:

"When the unconditioned stimulus is given, check that column and the first reaction column if a response is elicited. When the bell is rung without the shock being given, check the conditioned stimulus column; and if there is a response, check the second reaction column."

Discussion.

The best thing to be said for the apparatus described above is that it works. There have been subjects in whom it was found impossible to establish a conditioned response with this method. Such an outcome is to be expected, however, when one considers that there are so many disturbing conditions in a demonstration experiment of this sort. Watson found that there were subjects in whom he could not establish conditioned reactions when he employed a technique very similar to that used in this demonstration. There have been other subjects in whom the conditioned reaction was easily and very markedly established. With one subject twenty-one consecutive

SAMPLE RECORD SHOWING CONDITIONED REACTIONS

A. Reaction. *B.* Bell. *C.* Shock. *D.* Time.

conditioned responses were secured. The likelihood is that more responses would have been given by this subject if the experiment had not been stopped at that point. One other subject was so well conditioned to the sound of the bell that she was observed several hours later at home to react to the ringing of a telephone bell just outside her bedroom door with a widespread reflex movement as she lay half asleep.

One subject tested several weeks after he had been conditioned to react to the bell showed that the influence of the previous training was still strongly operating.

Subjects have been conditioned in spite of a deliberate attempt to inhibit responses to the bell alone. One subject commented; "I would figure out when the experimenter would give the shock and resolve not to move my finger. . . . About that time the bell would ring without any shock and up would come my finger. I seemed to have no control over that finger." One subject even wagered with his companions that he could not be conditioned. He lost the bet.

The demonstration has proved a very effective one. It is one of the most popular experiments in the laboratory courses. In the results obtained by using this apparatus one may find demonstrations of some of the special phenomena noted in conditioning such as fluctuations in the potency of the conditioned stimulus and waning of its effects, the effect of distractions, etc.

The apparatus described in this article was developed purely for demonstration purposes and is not devised for research. It has abundantly proved its worth for the uses stated.

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THE INFLUENCE OF FATIGUE ON TREMOR

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The term tremor is here used to designate rhythmic, alternating contractions of a muscle or group of muscles which occur at a frequency varying from about five to twelve per second. In 1872 Fernet observed the inverse relation of the frequency of tremor oscillations to their extent. This was confirmed by Eshner in 1897. In 1920 a positive statement of the effect of muscular exercise on tremor was given by Leon Binet. The second of Binet's six laws states, "Tremor increases as the result of muscular contraction and becomes exaggerated under the influence of work." The experiment to be described is concerned with these propositions of Fernet and Binet as they are involved in the change in tremor characteristics produced by several, equal, consecutive amounts of work.

Because of the technique used in measuring the tremors, it was necessary to construct a recording mechanism differing somewhat in design from those which have been used by other experimenters. The drum mechanism was dismantled from a spiral kymograph until there remained only the vertical revolving disk of about five and one-half inches in diameter. To the surface of the disk was attached a device for clamping smoked, octagonal glass plates also five and one-half inches in diameter. The plates were held parallel to the disk. The actual recording device consisted of a light aluminum heart lever pivoted so that the tip of the index finger of the observer could rest at a point two inches from the fulcrum, and a light celluloid point, on the opposite side, four inches from the fulcrum could touch the revolving, smoked

[1] The writer wishes to acknowledge an indebtedness to Dr. J. G. Beebe-Center for without his kindly interest and advice the present work would have been impossible.

glass. A fine piece of elastic attached at the point of contact of the finger, and stretched lightly on a supporting mechanism, fixed to the base of the lever fulcurm so that it was in a horizontal position and perpendicular to the lever, served as a return mechanism. The lever extended through a slot in a shield fastened to the base of the machine in such a way that the moving recording point could not be seen by the observer. A once per second timing device was attached to the kymograph so that the point of the marker was on the same radius as the lever point. The gears of the kymograph were adjusted so that the disk revolved at a rate of one revolution per minute.

When the tremor record was being taken the observer sat in a chair next to the table on which stood the kymograph. The arm of the observer was placed on a rest so that the index finger extended through a ring and the tip of the finger touched lightly the end of the heart lever. In this way the tremor was recorded over an interval of about one minute.

To secure sufficient magnification for examination, the plates, after being treated with a light shellac solution and cut in suitable dimensions, were placed in a stereopticon and projected on a screen. A magnification of twenty diameters was found to be sufficient. The projected record was first examined for rate, a summation being made of the upper peaks of the complete individual oscillations. Because of the irregularity of some of the tremor amplitudes, dividers were found to be helpful in stepping off the peaks. In spite of precautions taken, the figures given for the tremors of larger magnitude are necessarily somewhat more accurate than the figures given for the tremors of smaller magnitude. The usual procedure was to count the individual tremors over a period of twelve seconds to obtain an average. For the less clearly defined cases, the interval was sometimes extended to twenty-one seconds. A tracing was then made on paper of a four or five second interval in the record which appeared most representative, and an examination was made of amplitude and irregularity. Lines were drawn between the bases of all the individual tremors. The perpendicular distance from the base line to the highest point in the curve was

measured in units of a sixteenth of an inch. The units of amplitude appearing in the data accordingly represent about 1/640 of an inch of actual displacement. Besides the average amplitude, the standard deviation of the amplitudes was calculated, thus giving a measure of the irregularity. In this way, three separate characteristics of the tremor were measured in a way designed to be as objective as possible.

The procedure employed in obtaining the tremor records involved, as has been stated, the production of fatigue by determined amounts of exercise. Use was made of an ergograph which recorded the distance through which a weight of ten pounds was lifted. The subject rested his right fore arm on the table by which he sat during the whole experiment. The handle of the machine was grasped in the right hand. With the palm turned upward the handle was repeatedly raised by flexing the wrist until the required amount of work had been done. The tremor was taken from the right index finger. A normal record and three fatigue records were obtained from each subject. The work was limited as closely as possible to 1500 foot pounds distributed over three periods of 500 foot pounds. Tremor records were taken immediately after each period, and work was resumed as soon as possible to lessen the influence of rest. Four observers took part in the experiment.

The records were examined for rate, amplitude, and irregularity. A summary of the results is given in the table. Rates are designated by 'R,' average amplitudes by 'Av,' and standard deviations of the amplitudes by 'SD.' It may be seen that there is a fairly uniform increase in all of the characteristics considered.

Observer	Normal	1st 500 ft. lbs.	2d 500 ft. lbs.	3d 500 ft. lbs.
A	R = 8.08 Av = 1.06 SD = 0.25	R = 8.50 Av = 1.27 SD = 0.44	R = 9.00 Av = 1.56 SD = 0.60	R = 9.67 Av = 2.09 SD = 0.92
B	R = 7.25 Av = 1.96 SD = 0.74	R = 7.42 Av = 2.11 SD = 0.66	R = 7.92 Av = 2.04 SD = 0.88	R = 8.42 Av = 2.33 SD = 1.34
C	R = 8.83 Av = 1.89 SD = 0.72	R = 9.25 Av = 1.62 SD = 0.85	R = 9.36 Av = 2.29 SD = 1.05	R = 10.00 Av = 2.05 SD = 1.10
D	R = 8.33 Av = 1.41 SD = 0.62	R = 8.58 Av = 1.45 SD = 0.56	R = 8.75 Av = 1.39 SD = 0.66	R = 9.09 Av = 1.67 SD = 0.85

Change in Tremor Characteristics Due to Increasing Fatigue

The results of the records contradict the rule, proposed by Fernet and Eshner, of the inverse relation between rate and amplitude. It would seem rather that this relation varies with different experimental situations, for in another experiment performed by the writer, which involved the use of emotional stimuli, rate and amplitude varied inversely. In regard to Binet's law, a more definite formulation is made possible. Within the range of the experiment, it may be stated, "The rate, amplitude, and irregularity of tremor oscillations vary directly with the degree of fatigue."

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ELECTRICAL SKIN RESISTANCE BEFORE, DURING, AND AFTER A PERIOD OF NOISE STIMULATION

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Certain observations reported by the writer in an earlier publication (1) showed that the effect of a momentary noise stimulus on electrical skin resistance may last five minutes or ten or even longer. The present investigation was undertaken to study by means of these lasting effects, the course of electrical skin resistance during periods of rest, expectation, prolonged noise stimulation and subsequent quiet.

The measuring device used was that described by Davis and Porter (2) for measuring the galvanic reflex. The advantage of the instrument for the purpose is that it insures the passage of a constant measuring current through each subject, the importance of such constancy having lately been shown. The electrodes were the usual Zn-$ZnSO_4$-NaCl type. The first two fingers of the subject's hands were washed and waterproof tape was put around each at the top of the nail. When one finger was immersed in each electrode a constant area for any one subject during the experiment was exposed. Such a method, of course, does not make possible the direct comparison of one person's total resistance with that of another, since the area exposed varied from person to person. (Such a comparison was not desired for the purposes of this experiment.)

A subject for the experiment was seated by himself in a dark room at some distance from the recording room. The dark room, though far from sound proof, was relatively quiet because of its brick walls, isolated position and lack of windows. The size of the room, 15 × 25 feet, was not such as to make the subject feel cramped for space.

[1] Investigation conducted at University of Virginia, Institute for Research in the Social Sciences.

The noise used was produced by an electric doorbell, and an electric buzzer sounding together. These were located on a level with and adjacent to the seat of the subject's chair, their presence being known to the subject, but not their location.

The subjects were men and women college students, 43 in the experimental, and 24 in the control group. They were instructed at the beginning what the procedure in the experiment was to be.

After a subject in the experimental group had been placed in the dark room, current was turned on and allowed to flow for one minute before a reading was taken, because of the extremely rapid changes in skin resistance at the onset of current. At the end of a minute a reading was taken and a signal light—a red 10 watt lamp on a table opposite the subject—was turned on for three seconds. This stimulus occasioned a sudden drop in the resistance of practically all subjects (galvanic reflex), the maximum of which was recorded. The purpose of this flash was to determine the stimulating value of the light so that its value as a signal at the next flash might be determined. After the first flash of light resistance readings were taken every half minute without stimulation until five minutes had passed. Thirty seconds later the signal light was flashed for the second time and the maximum drop recorded. Thirty seconds after this signal another reading was recorded and the noise stimulus turned on and allowed to run five minutes during which resistance readings were taken every half minute. The maximum of the resistance drops at the onset and cessation of the noise were recorded. For four and one-half minutes after the end of the noise readings were taken every thirty seconds without further stimulation.

The procedure for the control group was the same except that no stimulation whatever was given.

The results were treated in the manner previously described (**2**) to express the readings in ohms of total resistance. The averages of each group are presented in Table I and Fig. 1. The curves of the experimental group divided into

TABLE I

AVERAGE OF RESISTANCE DURING EXPERIMENT

Number	Experimental Group	Control Group
0	27498 ohms	26495 ohms
.5	27069	25899
1	26288	25625
1.5	26657	25380
2	26337	24645
2.5	25819	24800
3	25538	24199
3.5	25553	24210
4	25371	24185
4.5	25183	23980
5	25080	23990
0	23862	24300
.5	22005	24295
1	22043	24320
1.5	22268	24300
2	22402	23950
2.5	22520	23515
3	22484	23615
3.5	22934	23205
4	22859	23110
4.5	22857	23040
5	22958	23030
.5	22758	22851
1	22519	22700
1.5	22459	22780
2	22194	22710
2.5	22210	22600
3	22380	22520
3.5	22140	22475
4	22189	22475
4.5	22148	22490
5	23041	

Average Resistance Drop	
After 1st signal	972
After 2d signal	1404
After onset	2553
After cessation	398

sexes are represented in Fig. 2 and the standard deviations of the groups are diagrammed in Fig. 3. The resistance drops immediately after stimulation are diagrammed in dotted lines, since these are averages of maximum deflections and of course do not represent the average resistance of the group at any definite moment.

The most striking feature of the curves in the diagrams is the considerable recovery of the experimental group during the noise stimulation and the apparent lack of any recovery at all after the noise had ceased. It can be seen that the onset of silence had, in fact, a certain stimulating value. At first glance it would seem as though the noise had an effect only

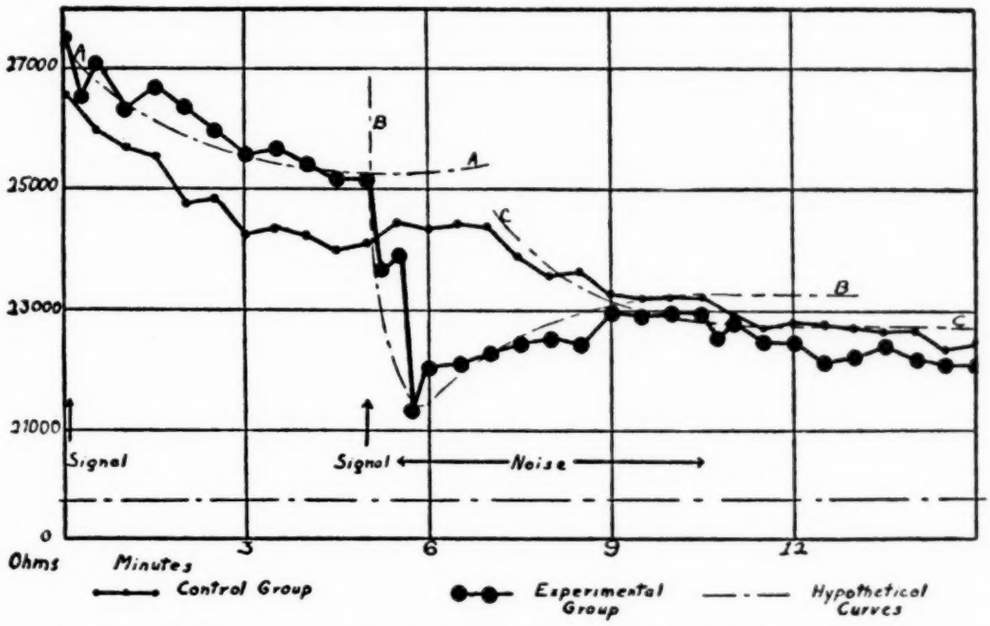

FIG. 1. Course of average resistance of control and experimental groups.

at its onset, but this is only apparent. There are other drops besides the initial one when individual cases are considered. Some of these, those that were of less than 30 seconds duration, would not be recorded. Others were recorded but smoothed out in the average, since they occurred at no definite points. The S.D. through this period shows the effect of these deflections by becoming wider after the first drop. The rise in resistance during the period, then, is due to two factors (1), the gradual decrease in the number and size of these drops, and the gradual building up of resistance, which is a much slower process than its falling in any galvanic reflex, as is shown by the equation (approximate) of the reflex curve.[2]

For an interpretation of the slightly decreasing resistance of the final period one must turn to the control group.

[2] $E = K\alpha te^{-\alpha t}$. α = reciprocal of rising period. t = time. e = exponential base. Gildemeister (3).

In the first period the control group curve falls below that of the experimental. Since electrode area was not the same for all subjects, no great importance can be attached to this difference. After an initial downward slope the control curve appears to reach a fairly stable plateau from the end of the third minute to the end of the seventh, showing even a slight tendency to rise. At the end of this plateau is another falling period. It would be convenient to analyze this curve therefore into two components similar to the *A* and *C* curves represented by dotted lines in Fig. 1. But the question must be considered whether the plateau is anything but an accidental deviation from a single curve. If a smoothed curve is drawn with reference to all the points of the control group, at least five consecutive observed points will fall above it, four being above by a distance about equal to the S.D. of the averages. Considering that there is one chance in five that each deviation is accidental, the chance of four being so (neglecting the fifth) is one in 625, or small enough to be negligible and make the consideration of a plateau obligatory.

Returning to the experimental group, it seems reasonable to suppose the existence of *A* and *C* curves there similar to those in the control group. The slight falling off of the experimental group curve in the last period is then to be considered as a manifestation of the *C* curve. The change of direction at the exact end of the noise period is then probably an accident, especially as the inflection point differs in one of the curves in Fig. 2. Adopting a process of subtraction one may arrive at some such curve as *B* in Fig. 1 to represent the actual effect of the stimulation (signal and noise being considered together). Since the control group in the first period averages over a thousand ohms lower than the experimental, and in the final period several hundred ohms higher, there is reason to believe that the experimental group in the final period has not yet returned to its 'normal' level, and a case can be made out for extending the *B*, or noise response curve throughout the final period.

The nature of the *B* curve is most obviously the response to the signal and noise, but the origin of the other two curves

is not so clear. The *A* curve is the familiar one found in most galvanic reflex experiments which deal with groups. It is usually regarded as due to the penetration of the electrolyte into the subject's skin. Another likely factor is the slowness of the ions in the tissues in reaching equilibrium. At the onset of current there is very rapid change in skin resistance attributable to movement of ions under an electric gradient. A certain amount of this movement would cause a small decrease in apparent resistance. Yet these two factors seem inadequate to explain the whole curve, since a certain proportion of the cases found in this, as in most experiments, show an actual increase in resistance. It would be hard to think of two such simple physical processes as those above mentioned reversing themselves in certain cases. It is suggested that an important factor in the falling of the *A* curve is excitation similar to that of the *B* curve but of less magnitude. It is well to point out that although no stimuli (other than the first signal) were intentionally introduced during this period, it would be a mistake to suppose that such a period is without stimulation, in this or other experiments. The strange situation, the contact with an experimenter who is a comparative stranger, the expectation of something about to happen, can hardly be overlooked as stimulating factors. Quite frequently subjects were observed to give a considerable number of galvanic reflexes during this period. The effect of these is almost certain to be cumulative, as are the reflexes following the signal and onset of noise at the beginning of the second period. The slight recovery of the control group from the 4.5 to the 7th minute lends some weight to the supposition of excitation, since this would represent the expected adaptation to the situation and recovery. The writer would be the last to claim excitation as the only factor involved in the descent of the resistance curve, but it does appear to be an important one.

The nature of the *C* curve is the most difficult to surmise. The time of its onset makes it hard to attribute to anything but excitation of some sort. No systematic introspective reports were taken, but ten of the control group reported that they began to feel bored or restless about half way through the

experiment. It seems likely then that the *C* curve is due to the discomfort of continuing in one position and desire for and expectation of the end of the monotonous experiment.

The responses to the two appearances of the light signal offer an interesting comparison. Both seem to have been given under the same conditions since the signal lamp was pointed out before the experiment, and a subject was as likely to be looking at it one time as another. The first resistance drop is attributable to the stimulating nature of the light itself and the second response, 44 percent greater than the first, indicates the stimulating value of the light with the meaning attached to it by the experimenter's words before the sitting.

FIG. 2. Course of average resistance for men and women.

In Fig. 2 the difference between the levels of the curves for men and women can of course be attributed, at least in part to the larger area exposed on the men's fingers. Granted equal resistance per unit area additional units of area would lower apparent resistance by acting as parallel resistors. A true sex difference (at least for this experimental group) is to be seen at the end of the noise period. The women recovered the level of their resistance before noise stimulation while the

noise was still in progress, but the men never did. Whether this difference represents a steeper slope to the recovery end of the women's *B* curve or the delayed onset of the *C* curve is a matter for speculation.

Figure 3 shows a steadily increasing standard deviation

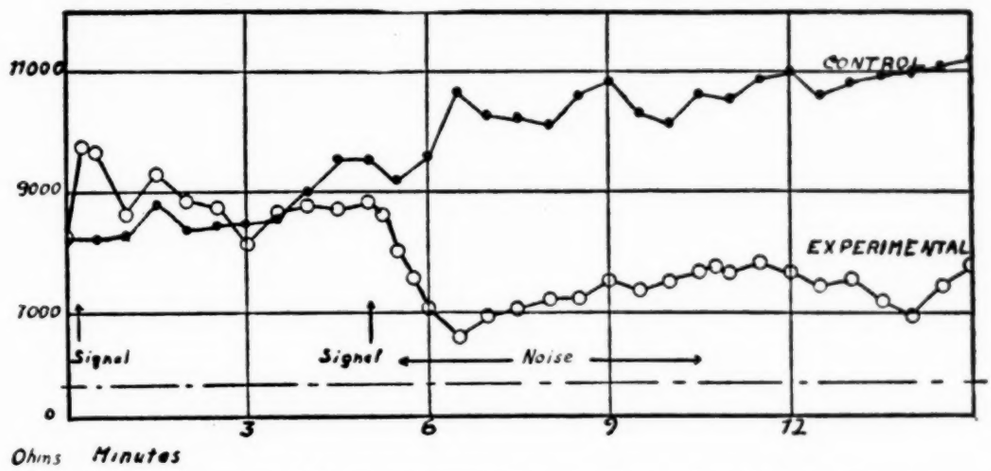

FIG. 3. Course of S.D. of resistance for experimental and control groups.

from the beginning to the end of the experiment for the control group. Evidently, there are great individual differences in behavior under the conditions of the experiment. Taken in conjunction with the rank order correlation of .734 between the first and final readings the curve of the S.D. indicates a strong tendency for those persons with high initial resistance to increase, and for those with lower initial resistance to decrease. This is found to be true despite the variable effect of skin area on resistance. This is explicable by supposing that a given individual has a constant factor of responsiveness. Those who are low in resistance at the beginning of the experiment have been responding more, and/or more readily to whatever stimulation they have encountered previous to the experiment and continue to respond so to the dark room, or whatever stimulating factor may be present in it. The converse would hold true of those with high initial resistance.

The standard deviation of the experimental group in general takes a course opposite to that of the S.D. of the control group. A possible explanation would be that conditions here were stimulating to all and caused greater absolute drops in subjects of high initial resistance. A notable fact is the

drop in S.D. during the period of stimulation, of such magnitude that the coefficient of variability is likewise decreased. It is to be noticed that the S.D. follows the trend of the average with a certain lag, reaching the minimum, for instance, about one minute later.

Whatever interpretation is put on the immediate physiological antecedent of the drop in resistance seems to make little difference for the purpose of the present experiment, although a number of recent investigations (4) (5) (1) have shown that the galvanic reflex is a matter of depolarization rather than simple extrusion of moisture, thereby coupling the phenomenon more directly to the activity of the sympathetic nervous system. It would be gratuitous to suppose the resistance drop under consideration to be of materially different nature from those briefer ones usually investigated. It is not yet known whether the long recovery period found in this experiment is a function of the reacting organ or of the sympathetic system or of both together. It is certain, however, from the nature of the present case that the adaptation evident is a function of the nervous system (or possibly receptor organ) since discharges into the reactor must be of decreasing frequency and magnitude in order to allow it to recover as it does.

Summary

An experiment was undertaken to determine the course of electrical skin resistance during the five minutes of noise stimulation and similar periods before and after such stimulation. A control group without stimulation was compared with an experimental group, readings being for every half minute. The results lead to the following conclusions.

A loud noise causes a sudden drop in the skin resistance, in this case of the order of 10 percent of the total.

Resistance shows a gradual recovery from this depression, a recovery interrupted in individual cases by other and smaller drops, this recovery taking place during the noise stimulation.

At the end of five minutes of homogeneous stimulation resistance does not recover from the effect of the noise, and evidence is presented to show the effect is still present 4.5 minutes after the cessation of noise.

The curve of the control group was analyzed into two components, the first attributed to physical effects and general stimulation, the second to restlessness. These components are taken to be present in the experimental group also.

A flash of light as a signal of the onset of noise caused a greater drop than a similar flash with no significance.

The group measured showed a sex difference in degree of recovery, that of the women being greater.

There are large individual differences in response to such procedure as used. Those with high initial resistance tend to increase and those with low to decrease, indicating a tendency to react constant for the individual.

The locus of the long continued depression of resistance was left undecided, but the adaptation shown must be a function of some part of the organism prior to the reacting organ.

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